PACIFIC SCIENCE

A QUARTERLY DEVOTED TO THE BIOLOGICAL AND PHYSICAL SCIENCES OF THE PACIFIC REGION

UNIVERSITY OF HAWAII PRESS

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Previous issue published November 26, 1957

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1/2   0   1 MILE
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PACIFIC OCEAN

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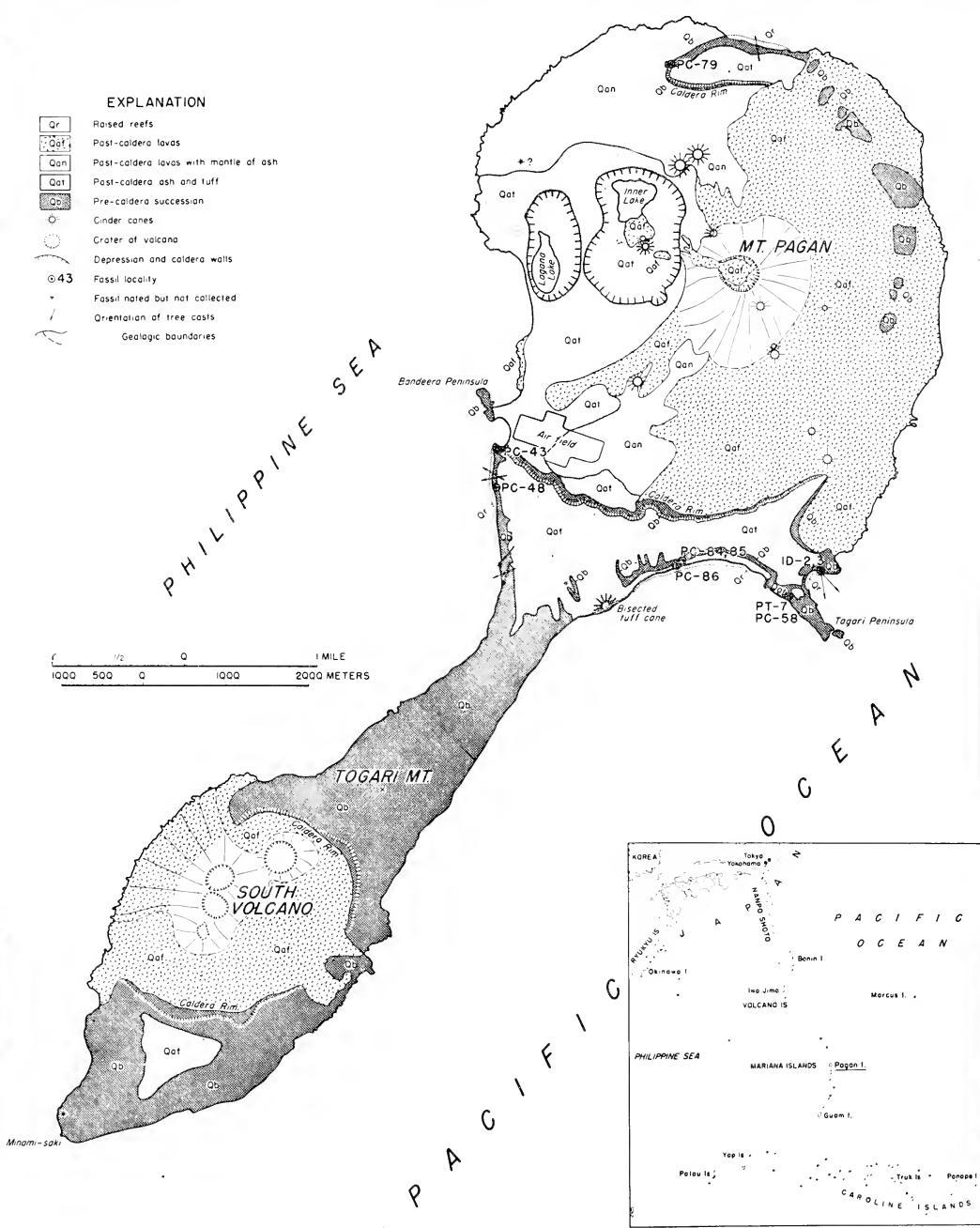Truk Is.
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FIG. 1. Generalized geologic map of Pagan, Mariana Islands.

A Fossil Flora from Pagan, Mariana Islands[1]

F. R. Fosberg[2] and Gilbert Corwin[3]

Pyroclastic deposits on Pagan, northern Mariana Islands, contain numerous plant impressions. During geologic investigations in 1954, ten collections were made for subsequent identification and study. Seventeen plant species, all of which now live in the Marianas, have been distinguished.

The geologic investigations of Pagan were undertaken by a field party of the Office of the Engineer, U. S. Army Forces, Far East, staffed by members of the U. S. Geological Survey. L. D. Bonham of the field party first noted the plant fossils. Gilbert Corwin, with the aid of M. J. Terman, also of the field party, and Santiago V. Castro, a resident on the island, collected samples and made field studies of the fossil localities. Fosberg has identified, studied, and described the plant impressions.

LOCATION AND GEOGRAPHY

Pagan Island is near the center and is the largest of the northern Mariana group. It lies between latitudes 18°01′ and 18°11′ North and between longitudes 145°41′ and 145°49′ East, about 280 miles north of Guam and 1,100 miles south-southeast of Tokyo, Japan (Fig. 1).

The northern Mariana Islands form a chain nearly 300 miles long that consists of the summits of large volcanoes rising from ocean depths of as much as 6,000 feet. Uracas (Farallon de Pajaros) at the north end is one of the most active volcanoes of the western Pacific. Pagan, Asuncion, Agrigan, and Guguan have had eruptions since 1900 (Tanakadate, 1940). The islands are generally small, relatively high, and rugged. The maximum

elevation of 3,136 feet is at the summit of Agrigan Volcano.

Pagan consists of two active volcanic centers located within broad circular depressions (calderas) that are connected by a high rugged isthmus. It has an area of 18.4 square miles and a greatest elevation of 1,890 feet near the south end of the isthmus.

The northern caldera is 3½ miles in diameter and has one large central cone, Mt. Pagan, that has an elevation of 1,855 feet. Relatively recent basalt flows are extensive and form broad plains north, east, and south of the volcano; ash is concentrated to the west (leeward).

The southern caldera is about 1½ miles across. South Volcano within it consists of four coalescing cones, three of which have broad steep-sided craters. Rough lava plains bound the volcano on the north, east, and south. To the west the volcano slopes directly to the ocean.

The isthmus ranges in width from about ½ mile at the north end to 1 mile at the south end. Northward along the crest of the isthmus, the peaks become successively lower. The caldera backslopes north of the isthmus are dissected by numerous valleys directed away from the rim of the northern caldera.

The volcanic rocks have been divided into two major groups: pre-caldera and post-caldera. Both consist of flows and pyroclastic rocks.

The older, pre-caldera group is well exposed in the caldera walls, along the coasts of the isthmus and southern end of the island, and in old sea cliff remnants north and northeast of Mt. Pagan (Fig. 1). The lavas and pyroclastic rocks are products of eruptions by at least four major volcanoes and a number of minor vents aligned along or near the axis of

the island. The largest of the old volcanoes was probably in the position of the present Mt. Pagan. The uppermost unit of the succession is composed of a widespread thick tuff-breccia sequence.

The pre-caldera group is probably of late Quaternary age. Sea cliffs have been cut in the breccias and older deposits; and reef limestones, some of which are now as much as 5 feet above present sea level, have since been deposited on the wave-cut platforms. Similar sea cliffs flanked by terraces and raised reef limestones have been noted on the coasts of many Pacific islands and are attributed to erosion and deposition during post-glacial high stands of sea level. Sea levels 5 to 12 feet higher than the present one have been assigned various dates ranging from about 1,000 to 5,000 years ago. Some plants that may have been introduced by man are represented by impressions in samples collected from the upper breccias and therefore may indicate a maximum age for these breccias of about 4,000 years—the probable length of time since the advent of man in Micronesia (Spoehr, 1955a, 1955b).

The post-caldera succession is concentrated within the calderas. At some places lavas have flowed over the caldera rims; tuff as much as 30 feet thick mantles large portions of the caldera blackslopes and the isthmus.

Historic records of eruptions are scattered, conflicting, and incomplete. It is likely that several major eruptions have taken place within the past 200 to 300 years. Marche (1891: 261) states that a major eruption occurred in 1872. Extensive lavas northeast and southwest of Mt. Pagan and a thick tuff sequence to the west were probably deposited at this time. Eruptions since 1900 have been minor.

VEGETATION

The present-day vegetation of Pagan gives a general impression of semi-aridity. This is probably not so much a reflection of climatic dryness as of an extremely porous substratum and of the pioneer nature of vegetation, which occupies surfaces of recent volcanic ejecta. In the very few low, wet areas, such as to the west and southwest of the Inner Lake, thickets of broad-leafed trees are luxuriant enough, and places bordering the lake are somewhat marshy. Luxuriant patches of woods also exist in hanging valleys on the west side of the south end of the island. A mixed scrub forest of low stature forms thickets and patches up to several acres in extent on plains north and south of Mt. Pagan — extending up its lower slopes in places on steep slopes on the west shore of the isthmus, and in numerous ravines throughout the island. There has been no investigation of the actual composition of this forest, but it contains 15 or more species of trees.

The loose volcanic ash that covers large areas, especially on the west side, is largely vegetated by an almost pure stand of swordgrass, *Miscanthus floridulus* (Labill.) Warb. This forms a coarse, harsh, brake-like grassland 1 to 3 m. tall and very dense in places. On the steepest slopes and above 250 m. altitude this grass tends to be shorter and the clumps more widely spaced. Above 450 m. it is sparse to absent.

Lava flows may be practically bare, as on the northeast side of Mt. Pagan; they may support scattered clumps of *Miscanthus* and trees of *Casuarina*, as on the east and southeast sides of Mt. Pagan and the central upland of the southern part of the island; or, as on many of the flows and lava cliffs to be seen along both sides of the island, they may be covered by almost pure forests of *Casuarina*. *Casuarina* and the fern, *Nephrolepis hirsutula* (Forst. f.) Presl, are among the earliest invaders on new lava. Both species were well established on a fresh black *aa* flow in the depression at the west base of Mt. Pagan in 1950. This flow has been dated by Tanakadate (1940) as having occurred in 1925. It shows no visible weathering.

On plains of ash soil the vegetation is gen-

erally grassland with scattered trees or clumps of trees. The trees may be *Pandanus, Casuarina*, or any of a number of broad-leafed species. Many of these areas were under cultivation before World War II and are weedy and have rows of *Casuarina* and other trees planted by the Japanese as windbreaks. *Jatropha gossypifolia* L., a fleshy-stemmed shrub introduced by the Japanese in the 1930's, has spread and now dominates large areas in the central part of the island. Clumps of trees of various kinds mark the sites of houses, still existing or not. On the gently sloping northwest part of the island is a large coconut plantation. There are smaller ones in many parts of the island, both on plains and on talus cones. Coconuts are also common in ravine mouths and on steep slopes above the sea. The large plantations are of relatively recent date, but there is no way of knowing the age of smaller clumps of coconuts that are mixed with other vegetation on various parts of the island. Some may very well date from before European visits to the island.

FOSSIL LOCALITIES

All samples of plant impressions are from the northern half of the island, mostly from tuff of the pre-caldera succession. Impressions were noted in talus blocks at the foot of a high cliff at the south end of the island but no specimens were obtained. One sample (PC-86) was collected from post-caldera tuffs forming the surface of a terrace northeast of the bisected tuff cone; other impressions in post-caldera deposits were observed on the uplands east of the cone.

Samples from the pre-caldera succession represent several stratigraphic horizons (Table 1). Most collections are from tuffs that underlie or are included in an extensive tuff-breccia sequence near the top of the succession. One of the most accessible localities (PC-43) is at a sharp bend in the trail at the west end of the caldera rim. Three samples (PC-58, PC-79, PT-7) are from tuffs associated with lavas or volcanic breccias that underlie the upper breccias.

Impressions of tree trunks were observed near the base of the upper breccias at several places (Fig. 2). In all cases the impressions are nearly horizontal and therefore represent fallen branches and trunks. Many are oriented about parallel to radii from Mt. Pagan, suggesting that a powerful explosion from the mountain felled the trees.

THE FOSSIL PLANTS

Almost the entire collection consists of leaf impressions, most of them fragmentary. Some of these have no features preserved that would make possible even tentative determinations. Very careful scrutiny shows that in the entire

FIG. 2. Tuff overlying lava and underlying tuff-breccia at the west end of the caldera rim. Plant impressions were collected from the tuff below and interbedded with the dark colored cindery layers in the upper part of the picture. The hole in the cindery layer was probably formed by decay of a tree trunk that had been buried by the ash. The sides of similar holes elsewhere commonly retain impressions of tree bark. A deformed tuff layer near the center of the picture may represent the soil horizon in which the plants grew.

TABLE 1

AGE SEQUENCE OF SAMPLES CONTAINING PLANT FOSSILS, COLLECTED ON PAGAN ISLAND

NUMBER	AGE AND LOCALITY*	LITHOLOGY	STRATIGRAPHIC RELATION
PT-7	Pre-caldera; Togari Peninsula.	Well-indurated, reddish, fine-grained, laminated tuff.	Tuff associated with breccia underlying thick flow and cinders of a minor vent; underlain by thick succession of lavas and pyroclastic rocks derived from old volcano to southeast.
PC-58	Pre-caldera; Togari Peninsula.	Same.	
PC-79	Pre-caldera; north end of island.	Poorly consolidated brownish tuff containing numerous pellets. Some fine-grained yellow to reddish soil layers associated.	Tuff overlain by pre-caldera lavas which are overlain in turn by the upper breccias. Underlying tuff breccias mostly covered by talus.
PC-43	Pre-caldera—base of upper breccia sequence; west coast, west end of caldera rim.	Poorly consolidated brownish to gray tuff and cindery tuff. Local coarse cinder beds (Fig. 2).	Overlain by 80-foot thick tuff-breccia sequence; underlain by 8 feet of tuffs that are underlain by lavas (Fig. 2).
PC-48	Pre-caldera—base of upper breccia sequence; west coast ½ mile south of monument on Bandeera Peninsula.	Same as PC-43.	Similar to PC-43.
PC-84	Pre-caldera—base of upper breccia sequence; east coast, ½ mile NE of bisected tuff cone.	Brownish, poorly consolidated, fine tuff.	Overlain by thin pellet tuff that is overlain by tuff-breccia; underlain by gray ash, a yellow-orange soil, and lava flow.
PC-85	Pre-caldera—within upper breccia sequence; same locality as PC-84.	Coarse, gray, poorly consolidated tuff with numerous large grains, rock fragments, and voids.	Overlain by tuff-breccia; underlain by pumice bed, 1-foot thick.
ID-2	Pre-caldera—base of upper breccia sequence; east coast, north side of Togari Peninsula.	Tuff similar to PC-84.	Overlain by thin tuffs that are overlain by tuff-breccias; underlain by ash, soils, and thick sequence of very fine tuff-breccia (lapilli tuff).
ID-3	Pre-caldera—within upper breccia sequence; specimens from talus blocks on slope.	Coarse, brownish tuff.	Near middle of tuff-breccia sequence; underlain by pumice bed, 1-foot thick.
PC-86	Post-caldera—recent tuff forming surface of terrace ½ mile NE of bisected tuff cone.	Brown, coarse, granular 6-inch tuff layer that is moderately indurated at surface but loose and friable a few inches below.	Overlain by pellet tuffs and locally by beach sands and wash; underlain by mixed loose ash and beach sand.

* See Figure 1.

collection less than 20 different species are distinguishable. Some species are represented by many pieces in various states of preservation.

In most instances the venation of the leaves provides the best distinguishing character. Margins are rarely well preserved and do not help much in identification. General shape, apparent texture, cross section, character of surface, and curvature are sometimes pertinent. It is obvious that with such material it would be hopeless to attempt identification

unless the probable flora were very restricted. The fact that the deposits are considered relatively recent makes reasonable the assumption that the flora was not much different from the present flora of the Marianas. It must be borne in mind, however, that any determination of material of this sort should be regarded as tentative. In the list that follows, those species which were not in any horizon represented by fairly well-preserved material are indicated by question marks. In the lists under the separate sample numbers, species not represented in the known present-day flora are marked by asterisks.

Those remains which presented no features that could suggest any hope for identification have been disregarded. Of the remainder the better specimens in all samples have been retained for deposit in the U. S. National Museum. Of these, all have been identified except two. One of these is probably a leaf scar of a compound leaf, which has not been matched; the other is either a mold of a fruit or an impression of a strongly curved or distorted leaf.

In addition to the specimens collected, molds of tree trunks, probably *Pandanus* judging from the abundant transverse leaf scars surrounding the trunks, were noted in several horizons.

In the following list of species the specimen numbers cited immediately below the name of each species are made up of the collector's sample number with an arbitrarily added number designating material of similar appearance in a sample and letters indicating the various pieces as labelled for deposit in the U. S. National Museum.

POLYPODIACEAE

Pteris quadriaurita Retz.

PC-79-1 (a–f)
Abundant fragmentary leaf impressions showing very clearly the shape and arrange-

ment of pinnules and fairly complete pinnae (Fig. 3).

This fern is widespread in the western Pacific and is found on Pagan today. It occurs in shaded places but at times under relatively dry conditions. It is surprising that such a delicate plant should be so well preserved.

PANDANACEAE

? Freycinetia mariannensis Merr.

PC-85-3, PC-79-5
PC-79-4 (a–k) (?)
Fragmentary leaf impressions (Fig. 4), very difficult to distinguish from those of *Pandanus tectorius*. Leaf veins 10 to 15 per cm., equally spaced clear to margin, little or no plication apparent, width up to 4 cm. Impressions showing neither plication, rolled margins, nor crowding of veins toward margins have generally been placed here. Some of these, however, where the venation is not clear, could possibly be *Pandanus tectorius*.

This species is found in the well-explored parts of the Marianas as far north as Pagan

FIG. 3. *Pteris quadriaurita*, fragmentary impression of frond showing portion of rachis, pinnae, with pinnules.

FIG. 4. ? *Freycinetia mariannensis*, portion of central section of leaf, showing venation.

and Agrigan. It has relatives throughout the Indo-Pacific region. It grows in woods and ravines and is a liana climbing on trees and rocks.

Pandanus tectorius Park.

(*P. fragrans* Gaud., *P. Kafu* Mart.)
PC-79–3 (a–h), PC-79–2 (?), PC-86–4 (a–f), PC-43–4 (a–d), PC-43–10, PC-43–11 (a–c) (?), ID2 (F)-6 (?), ID 2 (F)-2

Abundant fragmentary leaf impressions, many of them showing venation, many showing characteristic plications, some showing curled margins characteristic of dried leaves (as found under the trees), and several representing the narrow prolonged part near tip. Numbers PC-43–11 and ID2 (F)-6 seem to be fragments of the enlarged curved bases of the leaves, but this identification is not certain. Number PC-79–2 seems to be a fragment of an impression of a fruit of this species. This also is not certain. Margins have not been preserved in good condition in any of the material. The veins are generally more crowded especially near the margins, than in *Freycinetia*, varying from about 17 to 26 per cm. depending on the position in the leaf and are closer together toward the apex and near the margins.

The veins, except the midrib, are of about equal strength (Fig. 5).

The tree trunk molds seen probably also belong here.

This tree is very common on the Marianas, including Pagan, and is found throughout the tropical Pacific islands, mostly at low altitudes. It is an important component of many forests and is also found scattered in grasslands. Its frequency in this collection

FIG. 5. *Pandanus tectorius*, portion of central section of leaf.

could be due both to its abundance and to the hard stiff leaves that lend themselves to preservation as impressions.

GRAMINEAE

Miscanthus floridulus (Labill.) Warb. √

PC-43–6 (a–p), PC-43–7 (?), PC-43–8, PC-43–9 (a–b), PC-48, PC-79–7 (a–e), PC-79–8 (a–b), PC-84–1 (a–d), PC-85–4 (a–d), PC-36–5, ID2 (F)-1 (a–k), ID3$_1$-1

Abundant fragments of leaf impressions, as well as a few pieces of stem and leaf-sheath impressions. The leaves are thin and in addition to a heavy midrib have two orders of lesser veins, with the most prominent of these at equal intervals, about 9 to 6 mm. In each interval are 3 to 4 very distinct smaller veins. These blades are mostly 1 to 2 cm. wide, but several are much wider than that, so that it is hard to match them with available herbarium material. However, there seems little doubt that they represent this species. The sheaths show a curved surface, no midrib, and slightly irregular veins, about 16 in 5 mm. A mold of such a sheath shows a slight amount of compression and somewhat of a keel, or angle, as is commonly observed on the back of sheaths in this species. The poorly preserved stem fragments are not especially distinctive.

The leaves of this species are the most abundant fossils in the collection (Fig. 6). In some cases they are arranged so regularly as to suggest the pinnae of a palm or the plications of a fan palm leaf. The venation, however, is very characteristic and is easily matched in herbarium material.

This is the most abundant living plant on Pagan, where it dominates large areas of grassland, especially on loose volcanic ash soils. It is a coarse harsh grass as much as 2 to 3 m. tall. It is found from Japan and the Philippines to New Caledonia and east throughout Micronesia and Polynesia (except Hawaii) on volcanic islands.

PALMAE

Cocos nucifera L.

PC-79–6

This is the impression of a strongly plicate single bent section of a seedling leaf (Fig. 7). The size of the leaf and the amplitude and character of the plications match exactly a segment of a seedling coconut leaf preserved in the Bailey Hortorium of Cornell University. This leaf, if similarly bent, can be fitted into the plications of the fossil. Despite the scantiness of the material this species appears to be reliably identified.

The coconut palm is now very abundant on the island, mostly planted. It is generally regarded as being of human introduction on the oceanic islands of the Pacific, although
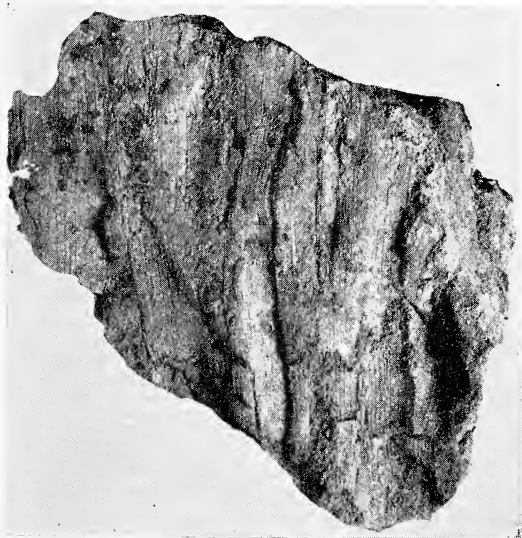

FIG. 6. *Miscanthus floridulus*, part of mass of leaf blades, showing venation.

FIG. 7. *Cocos nucifera*, portion of seedling leaf, showing plication.

the possibility of the establishment of drift nuts is not denied. In all probability the present seedling was from progeny of trees introduced by early human visitors to Pagan, indicating that the horizon in which it occurs may be rather recent.

ARACEAE

Alocasia macrorrhiza (L.) Schott

PC-43–1 (a–f), 2, 3, 5

A very well-preserved mold of a petiole, a fragment of the upper part of a petiole, various badly crushed and damaged petiole fragments and a stipule, not especially well preserved. Some of these petiole fragments would have been quite unidentifiable by themselves but were recognized when associated with the other better preserved parts (Fig. 8).
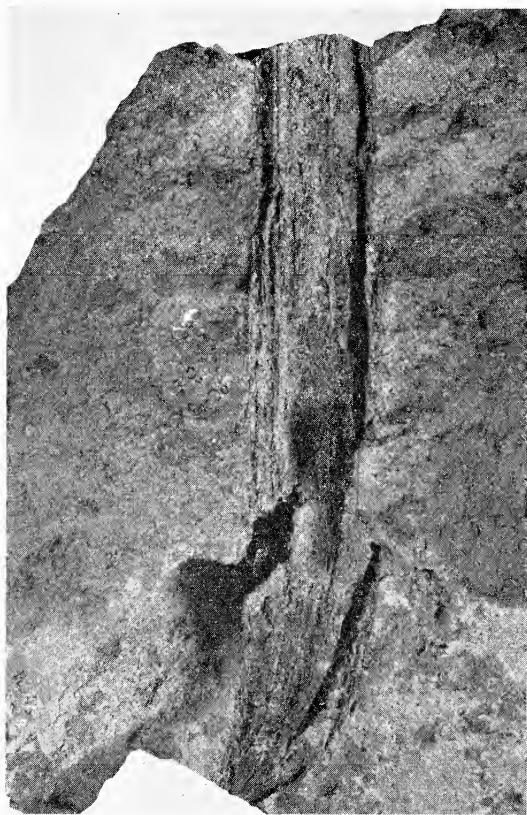
FIG. 8. *Alocasia macrorrhiza*, stipule.

This plant is found throughout the Pacific islands wherever man has carried it. It has not been found where it could not readily have been originally planted by man. The aborigines in many islands are said to utilize it as a famine food, though it is not very palatable. It has no obvious means of getting around unaided, but once established persists and multiplies rather successfully.

Its presence in this fossil flora is distinctly surprising. It indicates that the eruption producing the tuff, which preserved the remains, occurred after the earliest visits by man to the island.

LILIACEAE

? *Dianella ensiformis* (L.) DC.

PC-85–1, PC-85–2, ID2(F)-3, 4

Leaf blade impressions and fragments of impressions. Where the outline is preserved these taper more strongly than in *Miscanthus;* where venation is evident there is a prominent midrib and fine even venation, the veins of equal thickness, between 3 and 4 per mm. (Fig. 9).

This is not known from Pagan as a living plant, though it may well have been overlooked. It is common elsewhere in the Marianas in swordgrass vegetation on volcanic soils, especially on old erosion scars and around rocky places.

ORCHIDACEAE

? *Spathoglottis micronesiaca* Schltr.

ID2(F)-7

A reasonably well-preserved impression of a leaf fragment showing strong plication of about the magnitude of that shown by this species, the width and what remains of the shape, also, being correct. The specimen is 3 cm. wide and has just under 3 plications per cm. (Fig. 10).

This species is common in the grassland in the volcanic portions of Guam. It is not known at present on Pagan unless a pink-flowered plant noted but not collected by Bonham is it.

FIG. 9. ? *Dianella ensiformis*, leaf blades.

ULMACEAE

Trema argentea Planch.

PC-79-11

A partial leaf impression with palmate and net venation so perfectly preserved that there is little or no doubt as to its identity with *Trema argentea*. A piece of the opposing part of this impression is preserved on PC-79-12 (Fig. 11).

This plant, which is often and possibly correctly regarded as a variety of *Trema orientalis*, occurs throughout the Marianas, including Pagan, and north through the Volcano and Bonin islands, and with related forms in continental Asia.

It probably may be regarded as one of the few northern elements of the flora of the Marianas; and the present fossil fairly well disposes of the possibility of it being a recent introduction in the Marianas.

FIG. 10. ? *Spathoglottis micronesiaca*, portion of leaf blade showing plication.

HERNANDIACEAE

Hernandia sonora L.

PT-7-1

A portion of an impression of a leaf blade with major veins well shown and with some indication of texture. The appearance of a firm, stiff texture, palmate venation with veins somewhat impressed, and the distance between the base and the first branches from the midvein strongly suggest this species. It is a pantropic lowland or strand tree, common in the Marianas and known from Pagan.

EUPHORBIACEAE

? *Macaranga thompsonii* Merr.

PC-79-12

A poorly preserved impression of part of a leaf showing some major palmate venation.

FIG. 11. *Trema argentea*, portion of leaf, showing venation.

Viewed by itself it would be scarcely identifiable, but when placed side by side with a leaf of this species the correspondence of the venation pattern is striking.

This is a tree commonly found in the southern Marianas, especially in second growth and pioneer situations, but more often on limestone than on volcanic soils. It is not known to be living on Pagan at the present time.

Melanolepis multiglandulosa (Reinw.) Reichenb. f.

PC-86–2

A fragmentary leaf impression showing the main veins. The palmate and net venation pattern checks very well with that of this species, which is common on Pagan as in the rest of the Marianas, extending to Indonesia. It grows in thickets and secondary scrub forest.

MELIACEAE

Aglaia mariannensis Merr.

PT-7–3

Several imperfect impressions of leaflets, some showing pinnate venation. The veins are rather straight and strongly ascending. The shape of leaflets of this species varies from elliptic to obovate and that of the fossils shows corresponding variation as much as could be expected in the meager material available (Fig. 12*a*).

This is one of the commonest species of small trees in thickets as well as forests throughout the Marianas, including Pagan. Related species are found elsewhere in Micronesia and westward.

SAPINDACEAE

Tristiropsis obtusangula Radlk.

PC-58–1 (a–e), PT-7-2, 5

Impressions of leaflets, mostly imperfect, apparently somewhat folded along midribs, rather stiff, some of them showing main venation of a pinnate character. Some of the more poorly preserved of these impressions may belong to *Aglaia*, but the oblique bases of most of them scarcely fit that genus (Fig. 13).

Tristiropsis obtusangula is at present known only from Guam and Rota and grows usually but not always on limestone.

TILIACEAE

Elaeocarpus joga Merr.

PT-7–4

A practically perfect leaf impression, obovate, showing a short petiole and some venation (Fig. 12*b*).

This species extends throughout the Marianas as far north as Pagan. In the southern Marianas it grows on limestone but in the north on lava flows. It is a large forest tree. Closely related species are found in other parts of Micronesia and the Philippines.

FIG. 12. *Aglaia mariannensis*, impression on right, base of large leaflet, that on left, possibly one of smaller leaflets. *Elaeocarpus joga*, impression in center, leaf blade and petiole.

THEACEAE

? *Eurya nitida* Korth.

PC-79–10

Two fragmentary leaf impressions, not positively identifiable. Only bases, with some obscure venation, and rather curious minute surface marking are available. *Eurya* seems the most likely identity.

This is a small-leafed shrub or small tree, characteristic of volcanic soils and frequently found isolated or in small thickets in sword-grass areas. It has been reported from Pagan by Hosokawa as *Eurya ladronica* Hosokawa.

VERBENACEAE

Premna obtusifolia R. Br.

PC-86–1

A good leaf impression with venation rather clearly shown but lacking the apex

(Fig. 14). It is much smaller than the average for this species but matches well enough some of the smallest leaves present on available herbarium material. The angle of divergence of the main veins is so wide as to preclude its belonging to most of the other Micronesian species with palmate venation, the only possibilities being *Thespesia populnea* (L.) Sol. ex Correa, which it does not resemble in other characteristics and which is rarely so small, and *Sida fallax* Walp., which has never been reported from the Marianas.

Premna obtusifolia is a very common tree throughout the Marianas, including Pagan, growing in thickets or secondary growth as well as in original forest. The species is variable and extends over much of the Indo-Pacific region. It has been given various names, the one most commonly used for Marianas material being *Premna gaudichaudii* Schauer.

FIG. 13. *Tristiropsis obtusangula*, impression of leaflet, showing texture and venation.
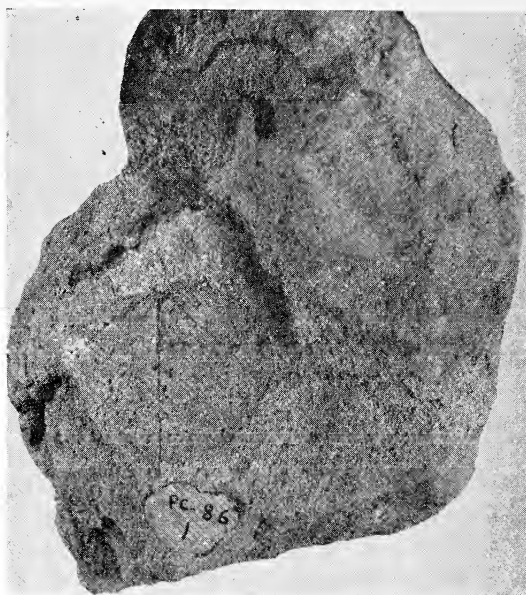

FIG. 14. *Premna obtusifolia*, an unusually small leaf blade, with apex missing, showing venation.

Family unknown

Unidentified impression, probably a leaf scar. ID2(F)-5

This is a concave impression, more or less shield shaped, with 5 (or 6) bundle traces. Unidentified mold of a fruit or curved leaf.

PC-86-3

This hollow curved impression, lacking suggestive details, was not matched with anything.

PALEOECOLOGY

By listing the species identified from each of the samples it is possible to suggest something of the probable ecological conditions and vegetation types at the time the various deposits represented were laid down. Such conclusions are, of course, extremely tentative when based on so few species. It is greatly hoped that at some future time more extensive collecting may be done in these beds so that the picture of the past vegetation and conditions on the island may become clearer.

Sample PC-43

Pandanus tectorius, Miscanthus floridulus, Alocasia macrorrhiza

It is hard to associate *Alocasia* with swordgrass except where the *Alocasia* might have been in a somewhat shaded ravine bottom, perhaps with *Pandanus* trees, and with the sides of the ravine covered with swordgrass, possibly extending down almost to the bottom of the ravine. On more level ground, if it is not too dry, the *Alocasia* could have grown in a thicket of *Pandanus* and possibly other trees, closely surrounded by swordgrass. The *Alocasia* suggests the presence or former presence of man, as this plant was in all probability distributed in the Pacific islands entirely through human agency.

Sample PC-48

Miscanthus floridulus

Probably swordgrass vegetation.

Sample PC-58

*Tristiropsis obtusangula

This is a forest tree, not now found on

* Not now known to be living on Pagan.

Pagan or in the northern Marianas but common on rough limestone on Guam. An association of plants similar to that in which this species grows on Guam occurs on rough lava in the northern Marianas on Alamagan Island, which is much like Pagan. Something like this association may have existed on rough lava in pre-caldera time on Pagan.

Sample PC-79

*Pteris quadriaurita, Pandanus tectorius, Freycinetia mariannensis, Miscanthus floridulus, Cocos nucifera, Trema argentea, ? *Macaranga thompsonii, ? Eurya nitida*

From the assemblage of plants represented here the habit could have been the margin of a mixed thicket, possibly second growth, bordering on swordgrass. The presence of a seedling coconut suggests the possibility of human disturbance.

Sample PC-84

Miscanthus floridulus

The vegetation indicated is swordgrass.

Sample PC-85

*? Freycinetia mariannensis, Miscanthus floridulus, *Dianella ensiformis*

Swordgrass vegetation close to either a thicket or a rock cliff, unless what are here identified as *Freycinetia* leaves are really *Pandanus*, in which case it would have occurred as scattered trees or thickets in the swordgrass.

Sample PC-86

Pandanus tectorius, Miscanthus floridulus, Melanolepis multiglandulosa, Premna obtusifolia Unidentified mold.

Probably swordgrass with mixed thickets or patches of scrub forest of *Pandanus* and broad-leafed trees.

Sample PT-7

*Hernandia sonora, Aglaia mariannensis, Elaeocarpus joga, ? *Tristiropsis obtusangula*

This association suggests a forest of the sort that grows on rough lava on such islands as Alamagan at the present day, or on rough limestone on the islands farther south.

Sample ID2 (F)

*Pandanus tectorius, Miscanthus floridulus, *Dianella ensiformis, *Spathoglottis micronesiaca* Unidentified leaf scar or fruit impression.

The conditions suggested by this small flora are those of swordgrass, possibly somewhat sparse, with either thickets or scattered trees of *Pandanus*.

Sample ID3$_1$

Miscanthus floridulus Probably swordgrass vegetation.

From the foregoing lists it will be seen that there is meager evidence for any comprehensive opinions on the past vegetation of Pagan. Most of the indications are that at least some of the vegetation was much the same as that found on the island today. Swordgrass occurs in all but the two lowest horizons, and there is little doubt that it dominated the vegetation wherever there was a loose ash substratum. Undoubtedly there were scattered trees or clumps of *Pandanus* and probably mixed thickets and scrub forest of *Pandanus* and other trees. Although the coconut does not appear in most of the lists of species, it may very well have been present in all of the later horizons, as there is little doubt that it was introduced by the early Chamorros and no reason why it would not have persisted whether or not they inhabited the island for any great length of time. An interesting fact is the complete lack of *Casuarina* in the collections. Next to *Miscanthus* it is the most abundant component of the modern vegetation of the island. It adds to the scanty evidence that *Casuarina* may be a recent arrival in the Marianas, but this is still an unsettled question.

The two lowest horizons, with plants commonly found on rough lava or rough limestone and with one tree not known today on Pagan, possibly represent a slightly more mature vegetation than any known at present on the island, though it may actually be represented in the mixed forest type. Something like it is prominent on extensive rough lava

flows on Alamagan, the next island to the south of Pagan. The violent explosive eruptions that formed the calderas and deposited the thick tuffs may have completely destroyed the stands of this type of forest.

The presence of four species in the fossil collections that are not known to be living on the island today may possibly have little significance, for the living flora has not been really well collected and those species may actually be present now. However, on an island with frequent and at times violent volcanic activity the continued existence of any but the most tenacious species of plants is hazardous, and it is more than likely that some that were once growing on Pagan may have been eliminated.

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Vascular Flora of Pagan Island, Northern Marianas[1]

F. R. FOSBERG[2]

THE ISLAND OF PAGAN is composed of two active volcanic mountains connected by a low isthmus. It is situated at about the center of the chain of young volcanic islands that make up the northern half of the Marianas at 18° 6'N., 145°45'E. Its flora is not very well known, and doubtless a fair number of species remain to be found there. In connection with the preparation of reports on the geology of the island (Corwin, *et al.*, ined.) and on a collection of fossil plants (Fosberg and Corwin, 1958) it has been necessary to bring together as completely as feasible the records of vascular plants found there to date.

Few botanical collectors have visited Pagan. Perhaps the first was A. Marche, who made general collections during a voyage to the Marianas in 1887 to 1889. There are a few specimens from Pagan in his collection which is at the Museum d'Histoire Naturelle in Paris. No comprehensive report on his plants has ever been published, and most of the specimens are only now being identified. It is not possible at this time to compile a complete list of his Pagan specimens, but those available are included here. The next visitor who left any botanical records was the German governor, G. Fritz, who made a voyage to the northern Marianas in 1901. He noted a few of the prominent plants, especially cultivated ones, and planted trees of several kinds on the various islands. His records, though not supported by specimens, are indicated in the following list by the symbol **Fr** in boldfaced type.

A long period with no botanical work on the island followed until the early 1930's, when the Japanese botanists became very active in Micronesia. In 1933 Prof. Ryôzô Kanehira made a short visit to Pagan, collecting a few specimens, several of which he reported in 1934 and the others in 1935. Prof. T. Hosokawa made two short visits in July and August, 1934, during which 42 plants were gathered. In 1934 he listed his own and previous records from all the Marianas, listing the islands for each species.

In 1949, under the auspices of the Pacific Vegetation Project, Mr. Donald Anderson spent a few days on the island and collected a fair number of species. A set of these will be deposited in the U. S. National Herbarium and others in the Bernice P. Bishop Museum and the New York Botanical Garden. In 1950, I was able to spend a day on the island and collected a number of specimens, sets of which will be deposited in the same herbaria. During a geological study of the island in the summer of 1954, Mr. L. D. Bonham, of the U. S. Geological Survey, collected 40 specimens in order to obtain identifications of plants mentioned in his account of the vegetation (in Corwin *et al.*, in preparation). His specimens will be deposited in the U. S. National Herbarium. One sight record by G. L. Corwin is included.

On the basis of these collections and records there are at present 168 species and varieties of vascular plants known from the island, 101 of which are probably indigenous, 8 (at least) of aboriginal introduction, and 59 probably of post-European introduction. In addition to these, 4 other species are recognized only as fossils (Fosberg and Corwin, 1958). In the following list specimens are not

cited, as I plan to publish an annotated catalog of the flora of Micronesia, in which all specimens seen will be cited. Neither a description of the island nor of its vegetation are included as these will be given in a paper on the fossil plants (Fosberg and Corwin, 1958). After each species the workers who have recorded or collected it on Pagan are designated by the following symbols in bold-faced type:

Marche	M
Fritz	Fr
Kanehira	K
Hosokawa	H
Anderson	A
Fosberg	Fo
Bonham	B
Corwin	C

The nomenclature is that presently accepted by me and not necessarily that under which the original reports were made.

The indigenous flora is almost entirely an attenuation of that of the Marianas group to the south, some of the species extending northward to the Bonin Islands. *Trema argentea* and *Myoporum boninense* may possibly be plants that have spread from the Bonin Islands southward in prehistoric time, though a spread in the opposite direction is entirely possible, as both species are known from Saipan. *Fimbristylis urakasiana* has previously been regarded as endemic on Uracas, the northernmost of the Marianas. It is very likely present at least on all of the recent volcanic islands of the group, but they have not been adequately enough studied and collected to detect all plants present, especially in such groups as *Fimbristylis*. Of the species and varieties, both recent and fossil, 20 are probably endemic to the Marianas and 3 more to the Mariana, Volcano, and Bonin islands. The remainder are widespread species, mainly of lowlands and strands of the Indo-Pacific area, a few of them almost pantropic. These figures are probably valuable only as a general indication of the distributional relations on a rather young volcanic island. When more

complete collections have been made, both on Pagan and on the other northern Marianas, more reliable and significant conclusions may be reached as to the origin of the flora of this area.

SYSTEMATIC LIST OF SPECIES

* Indicates recently introduced species; † indicates species believed to be of aboriginal introduction.

Gleichenia linearis (Burm. f.) C.B.Cl.   Fo
Cheilanthes tenuifolia (Burm.) Sw.   H, Fo
Acrostichum aureum L.   H, Fo
Asplenium laserpitiifolium Lam.   H
Asplenium nidus L.   A
Asplenium unilaterale Lam.   H
Davallia solida (Forst. f.) Sw.   H, A
Dryopteris unita (L.) O. Ktze.   Fo, B
"Lastrea" torresiana (Gaud.) Moore   A, Fo
Nephrolepis hirsutula (Forst. f.) Presl H, A, Fo, B
Polypodium scolopendria Burm. f.   H, Fo, B
Pteris quadriaurita Retz.   H, Fo
Sphenomeris chinensis (L.) Maxon   Fo
Psilotum nudum (L.) Griseb.   H
Freycinetia mariannensis Merr.   H, A
Pandanus dubius Spr.   H
Pandanus tectorius Park.   K, H, A, B
*Cenchrus brownii R. & S.   A
*Cenchrus echinatus L.   A
*Chloris inflata Link   B
Chrysopogon aciculatus (Retz.) Trin.   A, Fo, B
*Cynodon dactylon (L.) Pers.   A, B
*Dactyloctenium aegyptium (L.) Willd.   H, A, Fo, B
*Digitaria ciliaris (Retz.) Koel.   Fo
*Eleusine indica (L.) Gaertn.   A, Fo
*Eragrostis amabilis (L.) W. & A.   H, A, Fo
Heteropogon contortus (L.) Beauv.   A, Fo
Miscanthus floridulus (Labill.) Warb. H, K, A, B
Panicum ambiguum Trin.   A, Fo
*Paspalum conjugatum Berg.   Fo
Paspalum orbiculare Forst. f.   A, Fo
*Pennisetum purpureum Schumach   Fo
Sporobolus virginicus (L.) Kunth   A, B
Thuarea involuta (Forst. f.) R. & S.   H
*Zea mays L.   Fr

Zoysia tenuifolia Trin.   A, Fo
*Cyperus compressus L.   A, B
 Cyperus cyperinus (Retz.) Vahl.   A
 Cyperus javanicus Houtt.   A, Fo
 Cyperus polystachyos Rottb.   Fo
 Fimbristylis annua (All.) R. & S.   A
 Fimbristylis cymosa R. Br.   A
 Fimbristylis urakasiana Kük.   Fo
 Scleria lithosperma (L.) Sw.   A
†Alocasia macrorrhiza (L.) Schott   H, Fo, B
†Colocasia esculenta (L.) Schott   Fo
*Xanthosoma sagittifolia Schott   A
†Areca cathecu L.   C
†Cocos nucifera L.   Fr, B
*Ananas comosus (L.) Merr.   Fr, A, Fo, B
*Agave americana L.   B
*Agave sisalana Perr.?   A
 Dianella ensiformis (L.) DC.   (Fossil only)
*Crinum sp.   H
 Curculigo orchioides Gaertn.   H, K
*Hymenocallis littoralis (Jacq.) Salisb.   A,
  B
†Tacca leontopetaloides (L.) O. Ktze.   H,
  A
†Musa sapientum L.   Fr, H, B
 Spathoglottis micronesiaca Schltr.   (Fossil
  only)
 Taeniophyllum mariannense Schltr.   H
 Casuarina equisetifolia L.   Fr, H, A, Fo, B
 Trema argentea Pl.   H, K, A, Fo
 Boehmeria celebica B.   H
 Pipturus argenteus (Forst. f.) Wedd.   H, A,
  B
†Artocarpus altilis (Park.) Fosb.   Fr, H, A,
  B
 Ficus prolixa var. carolinensis (Warb.)
  Fosb.   H, A, Fo, B
 Ficus tinctoria var. neo-ebudarum (Summ.)
  Fosb.   H, A, Fo, B
*Achyranthes aspera L.   H
*Amaranthus spinosus L.   Fo
 Boerhavia diffusa L.   H
 Sesuvium portulacastrum L.   A
*Portulaca oleracea L.   A, Fo
 Portulaca samoensis var. Poelln.   H, A, B
 Guamia mariannae (Saff.) Merr.   K, H, K,
  A
 Cassytha filiformis L.   H
 Hernandia sonora L.   H
 Capparis cordifolia Lam.   A
 Abrus precatorius L.   M, H, A, Fo

 Canavalia sericea Gray   H, B
 Cantharosperumum scarabaeoides (L.)
  Bail.   H
*Cassia lechenaultiana DC.   K, A
*Cassia occidentalis L.   A, Fo
*Cassia tora L.   H
*Crotalaria mucronata Desv.   A, Fo
*Crotalaria trifoliastrum Willd.   H, H
*Delonix regia (Boj.) Raf.   B
*Desmodium triflorum (L.) DC.   H, A, Fo
 Erythrina variegata var. orientalis (L.)
  Merr.   H, A
 Glycine clandestina Wendl.   H, H
 Mucuna gigantea (Willd.) DC.   A
 Mucuna pruriens (L.) DC.   H
*Pithecellobium dulce (Roxb.) Benth.   K,
  A, B
 Vigna marina (Burm.) Merr.   H, K, A
*Citrus sp.   C
*Euphorbia hirta L.   H, K, A, Fo
*Euphorbia prostrata Ait.   Fo, B
*Euphorbia thymifolia L.   A, Fo
*Jatropha curcas L.   A
*Jatropha gossypifolia L.   A, Fo, B
 Macaranga thompsonii Merr.   (Fossil only)
*Manihot esculenta Crantz   A
 Melanolepis multiglandulosa var. glabrata
  (M.-A.) Fosb.   H, Fo, B
 Phyllanthus mariannensis M.-A.   H, K
*Phyllanthus niruri L.   A, Fo
 Aglaia mariannensis Merr.   H, A, Fo
*Mangifera indica L.   B
 Tristiropsis obtusangula Radlk.   (Fossil
  only)
 Colubrina asiatica (L.) Brongn.   H, A
 Elaeocarpus joga Merr.   H, K
 Grewia crenata (L. f.) Schinz & Guill.   M,
  H, A, Fo
*Triumfetta semitriloba Jacq.   A
*Gossypium hirsutum L.?   A, B
 Hibiscus tiliaceus L.   H, A, Fo, B
*Sida acuta Burm. f.   H, A, Fo
*Sida rhombifolia L.   M, H, Fo
 Thespesia populnea (L.) Sol.   A
 Urena lobata L.   H
*Ceiba pentandra (L.) Gaertn.   A
 Melochia sp.   A
 Calophyllum inophyllum L.   A
 Ochrocarpos odoratus (Raf.) Merr.   H
 Eurya nitida Korth.   H
*Carica papaya L.   A, Fo

*Passiflora foetida var. hispida (DC.) Killip. A, Fo, B

Pemphis acidula Forst.　H, A

Terminalia catappa L.　H, A

Eugenia reinwardtiana DC.　A

*Psidium guajava L.　A

Barringtonia asiatica (L.) Kurz　H, A, B

Melastoma malabathricum L.　Fo

Polyscias grandifolia Volk.　H, A

*Polyscias scutellaria (Burm. f.) Fosb.　Fo

Centella asiatica (L.) Urb.　H

Lysimachia mauritiana Lam.　H, H

Discocalyx megacarpa Merr.　H

Pouteria obovata (R. Br.) Baehni　H, A

Geniostoma micranthum DC.　K

Jasminum marianum DC.　A

Bleekeria mariannensis (A. DC.) Koidz. K, H, K, A

Cerbera dilatata Mgf.　H, A

Ochrosia oppositifolia (Lam.) K. Schum. H, A, B

*Thevetia peruviana (Pers.) Merr.　A, Fo

*Ipomoea aquatica Forsk.　Fo

*Ipomoea batatas (L.) Poir.　Fr, A, Fo

Ipomoea pes-caprae (L.) Sweet　H, A, Fo, B

Operculina ventricosa (Bert.) Peter　M, Fo

Heliotropium ovalifolium var. depressum (Cham.) Merr.　Fo

Messerschmidia argentea (L. f.) Johnst.　H

*Hyptis pectinata (L.) Poir.　Fo

*Hyptis capitata Jacq.　H

*Hyptis suaveolens Poir.　H

Callicarpa candicans (Burm. f.) Hochr.　H, A

Callicarpa lamii Hosok.　M, A

Premna obtusifolia R. Br.　H, K, A, Fo, B

*Stachytarpheta indica (L.) Vahl　A, Fo

Vitex negundo L.　H

Myoporum boninense Koidz.　A

Hedyotis foetida var. mariannensis (Merr.) Fosb.　H, A

*Morinda citrifolia L.　H, A, B

Psychotria mariana Bartl.　H, K, A, Fo, B

Randia cochinchinensis (Lour.) Merr.　A

Scaevola frutescens (Mill.) Kr.　H, A

*Ageratum conyzoides L.　Fo

*Elephantopus mollis H. B. K.　K, A, Fo

*Emilia sonchifolia (L.) DC.　A, Fo

Glossogyne tenuifolia Cass.　H, K, Fo

*Synedrella nodiflora Gaertn.　H, K

*Vernonia cinerea (L.) Less.　H, A, Fo

Wedelia biflora (L.) DC.　H, A, Fo

Wedelia biflora var. canescens (Gaud.) Fosb.　A

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Oceanographic and Meteorological Aspects
of the Gulf of California[1]

GUNNAR I. RODEN

THE PRIMARY OBJECT of the present paper is to give an adequate description of the climatic and oceanographic conditions in the Gulf as they are known today.

Only a few authors have discussed the Gulf (Sverdrup, 1940; Osorio Tafall, 1944) and only the geological work was described in detail (Anderson, 1950; Durham, 1950; Natland, 1950; Revelle, 1950; Shephard, 1950).

The data used in the present investigation are largely taken from the "E. W. Scripps" expeditions in 1939 (Sverdrup and staff, 1943) and from the publications of the Servicio Meteorológico Mexicano, the U. S. Coast and Geodetic Survey, and the U. S. Hydrographic Office.

The data for the Gulf are few and the conclusions that can be drawn from them are necessarily limited and should be taken only as a first approximation until more and better data are at hand.

The Gulf of California is of considerable interest both scientifically and economically,

and it is expected that its importance will steadily increase in the future, especially as an additional food source for Mexico. A thorough knowledge of the physical and chemical changes taking place in the Gulf is essential to the understanding of its fisheries.

Moreover, the Gulf is interesting because it represents the only large evaporation basin of the Pacific Ocean and because it shows certain differences from other comparable evaporation basins. A final answer to all the different problems in the Gulf cannot be expected from the meager data available but it is the hope of the author that this paper may stimulate more research in this intriguing area.

ACKNOWLEDGEMENTS

FIG. 1. Bathymetric map of the Gulf of California.

GENERAL DESCRIPTION AND PREVIOUS INVESTIGATIONS

The Gulf of California is unique in many respects. Lying as it does in a predominantly arid region it comprises the only large evaporation basin of the Pacific Ocean. It is roughly rectangular in shape and lies between the Mexican states of Baja California to the west and of Sonora and Sinaloa to the east. At its southern end the Gulf is in open communication with the ocean. The length of the Gulf is about 1400 km. and the average width about 150 km., giving a total surface area of roughly 210,000 km.², if the southern boundary is taken along latitude 23°N. Between this latitude and a line joining Cabo San Lucas with Cabo Corrientes (Fig. 10) lies a transition region which occasionally is in-

fluenced by Gulf water (Schott, 1935). This region will be called the Gulf Entrance, and it has a total surface area of roughly 40,000 km.²

Topographically the Gulf can be divided into a number of basins, separated from each other by transverse ridges. The deepest basins have a maximum depth of more than 3000 m. and a sill depth below 1500 m. (Geol. Soc. Amer., Mem., 1950). In the northern part of the Gulf isolated basins are found in which different hydrographic conditions prevail (Sverdrup, 1941). These basins seem to represent deep depressions in an otherwise quite narrow shelf and are completely isolated below 200 to 300 m. Their isolated character is quite sufficient to explain the hydrographic conditions found in them and it is not neces-
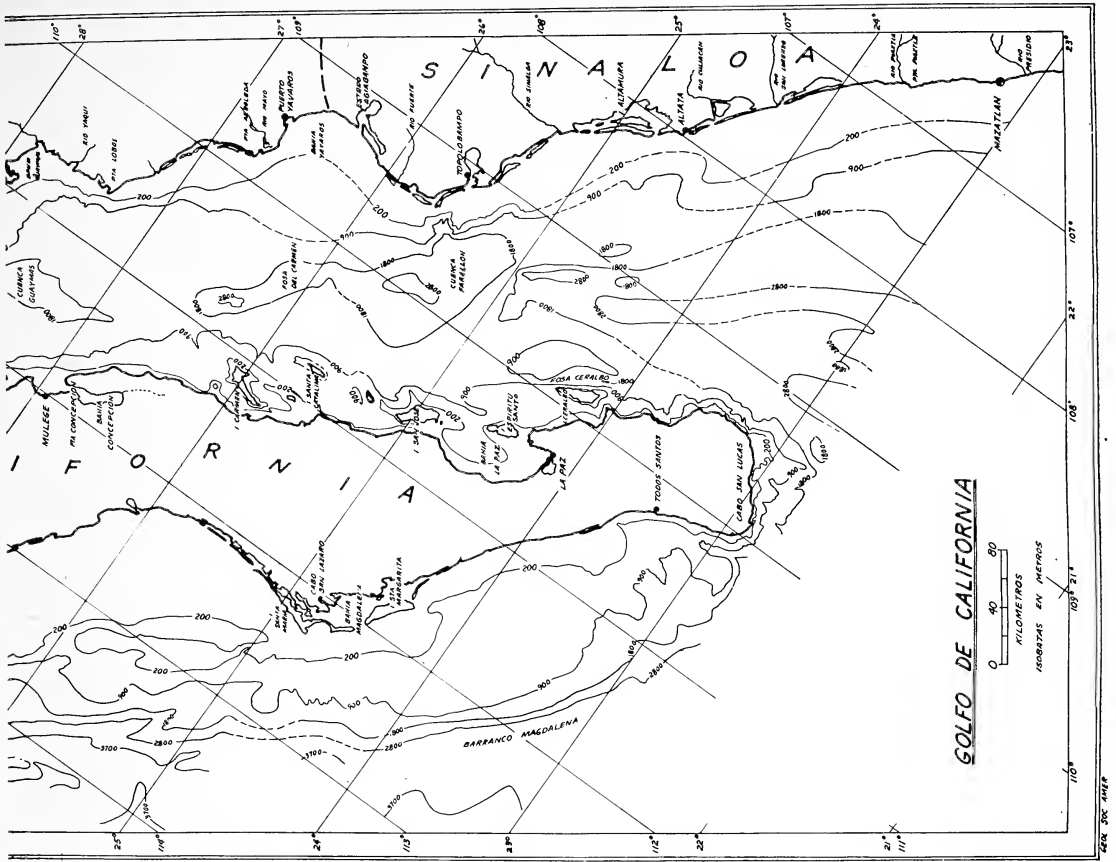
FIG. 1. Bathymetric map of the Gulf of California (*continued*).

sary to assume the existence of a ridge running SSE between Angel de la Guarda and Tiburón to account for the differences (Sverdrup, 1941). There are two large islands in the Gulf—Angel de la Guarda and Tiburón—both with elevations exceeding 1500 m.

The coast along Baja California is very steep and flanked by numerous islands and rocks. Off Rio Colorado and northern Sonora the coast is less rugged and possesses a wide shelf. Along Sinaloa the shelf narrows again and disappears at Cabo Corrientes.

The Gulf remained scientifically unknown until fairly recent times. Prior to the coming of the conquistadores, the Gulf area was inhabited by different Indian tribes who lived by fishing and undoubtedly had some local knowledge of the currents and the general

appearance of the water. Their observations are, however, lost because they had no written records.

With the coming of the Spaniards, trade developed between Gulf ports and the Far East (Hakluyt, 1598) and various captains entered the Gulf with lead and line. The first written records are therefore found in the ships' logs of the early seafarers. Scientific exploration began in 1889 when the U. S. Fish Commission steamer "Albatross" (Fig. 2) entered the Gulf to make a few hydrographic stations, especially in the northern part (Townsend, 1901). The data collected at these stations consisted of temperature and density determinations, the latter being made with a hydrometer. The results of the expedition (not previously published in this form) are shown in Figure 3.
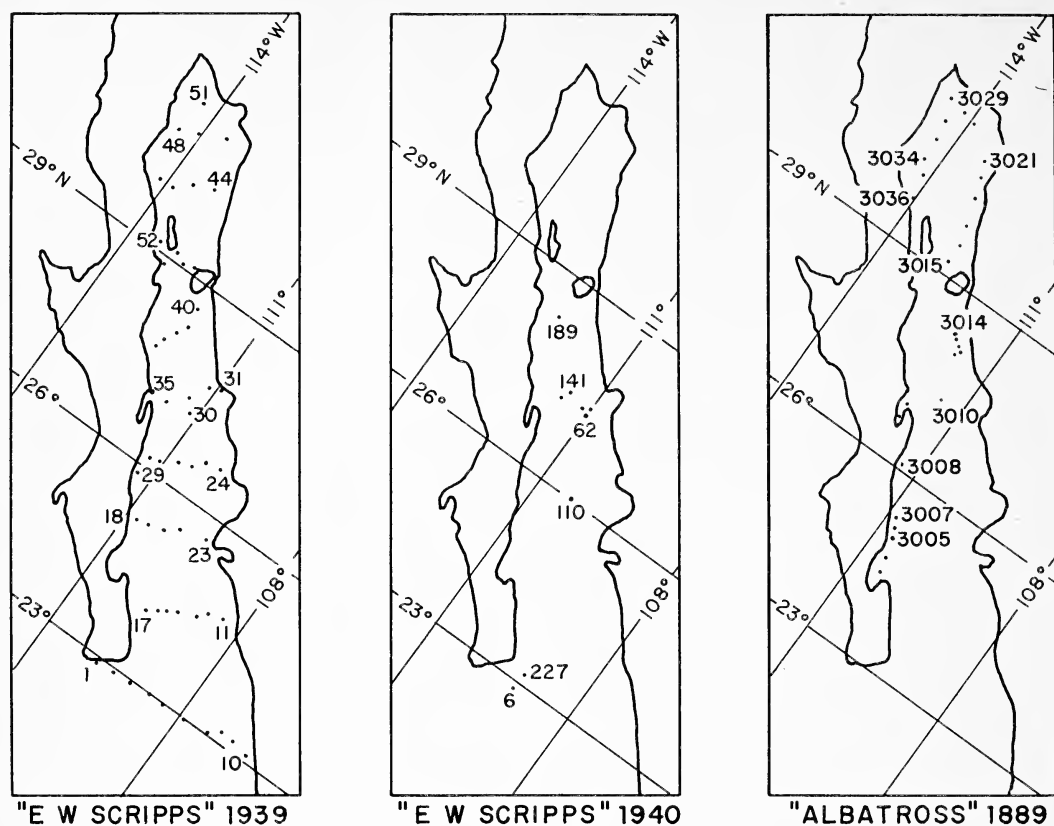
FIG. 2. Stations occupied on previous expeditions.

Considerable warming and high salinity were found in shallow bays such as Bahia Guaymas and Bahia Concepcion. Upwelling was characteristic along the northern coast of Sonora where the temperature was about one degree lower and the salinity 0.4°/₀₀ lower than in the neighborhood offshore. Near the mouth of Rio Colorado the salinity varied between 35.2 and 35.7°/₀₀, probably due to the admixture of fresh water. The bottom temperatures in the northern part everywhere exceeded 11°C. and the bottom salinity varied between 35.5 and 36.1°/₀₀.

The next important description of the Gulf of California was made by Thorade (1909) in a paper on the California Current. He examined a great number of ship logs over many years and was the first investigator to draw monthly surface temperature charts (Fig. 4)

for the southern part of the Gulf and deduce from them the general circulation in the Gulf and to correlate the sea surface temperatures to the direction of the wind, the orientation of the shore line, and the special climatological conditions prevailing in the Gulf. His main conclusions were that the temperature of the Gulf is independent of the temperature in the adjacent ocean and that the low temperatures along the east coast in winter are the result of northerly winds that tend to transport surface water away from the coast and thus produce upwelling. He also observed correctly that during most of the year the circulation is counterclockwise in the Gulf and that the water enters the Gulf along the east coast and leaves it along the west coast. He mentioned that "manifold discontinuities are observed by a sudden change in tem-
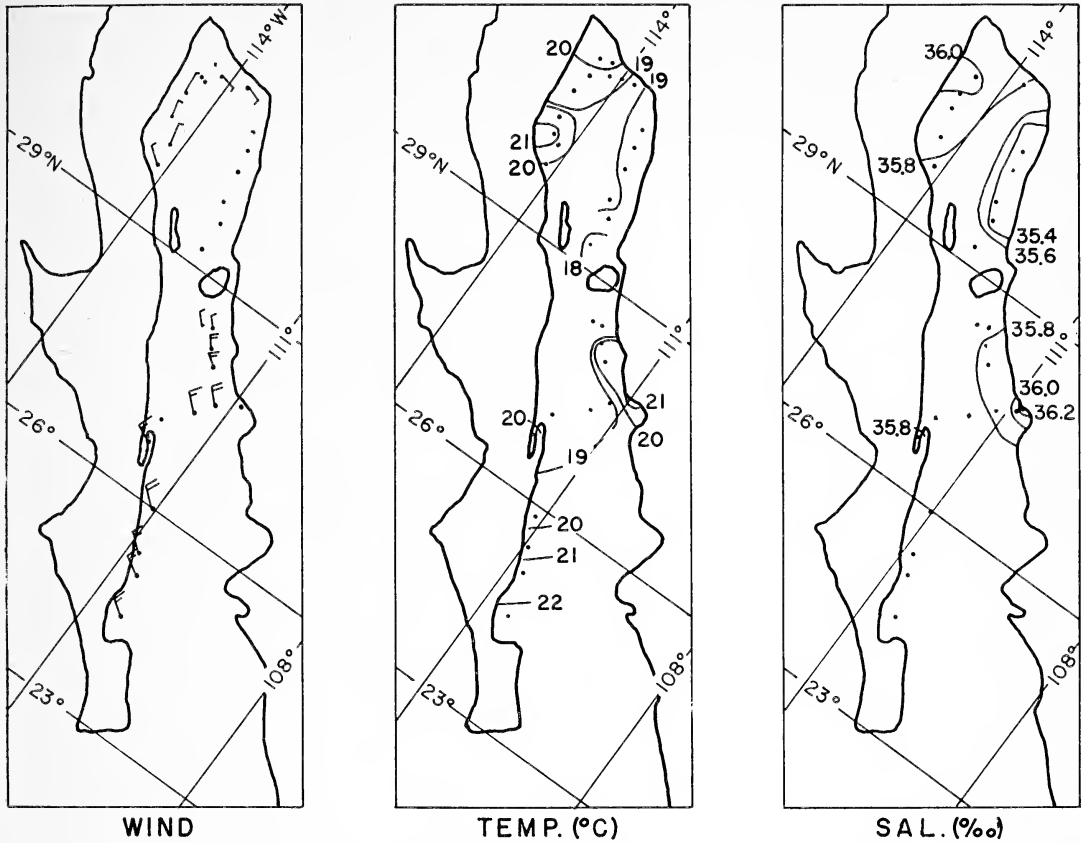
FIG. 3. Distribution of winds, temperature, and salinity in March, 1889.

perature" in the vicinity of Cabo San Lucas, which might well have been the first description of the San Lucas front.

Schott (1935: 208) described the Gulf of California as part of the Mexican region, a region defined roughly as lying between the Gulf of Tehuantepec and Cabo San Lucas and extending seaward between the California Current and the North Equatorial Current. The Mexican region is characterized by a very high surface temperature and very weak circulation. He briefly mentioned the temperature discontinuity near Cabo San Lucas and drew attention to the frequent hurricanes in that region.

In the spring of 1939 the Scripps Institution of Oceanography sent an expedition into the Gulf led by H. U. Sverdrup on the "E. W. Scripps." Fifty-three stations were made in the

Gulf (Fig. 2) taking temperature, salinity, oxygen, calcium carbonate and plankton observations on each station from the surface to the bottom (Sverdrup and staff, 1943). These data are still the most complete ever taken in the Gulf. Sverdrup's main conclusions were that the Gulf can be subdivided into two parts, a northern part and a southern part, separated from each other by a submarine ridge which comes to within 200 m. below the surface. The water mass to the north is largely of local origin and formed by convective currents in winter, the water to the south is nearly the same as in the adjacent ocean and only modified slightly at the surface by extensive evaporation (Sverdrup, 1941).

In late fall of 1940 the "E. W. Scripps" made a second trip to the Gulf. The chief
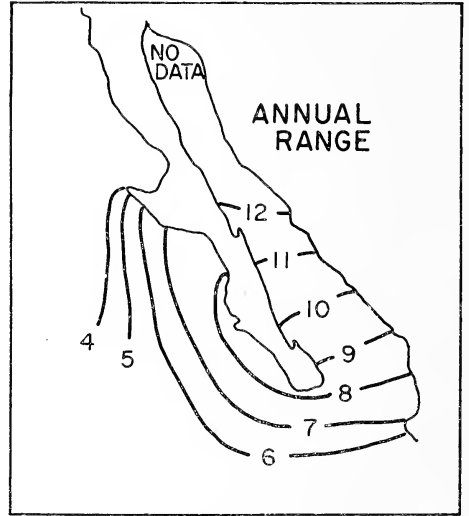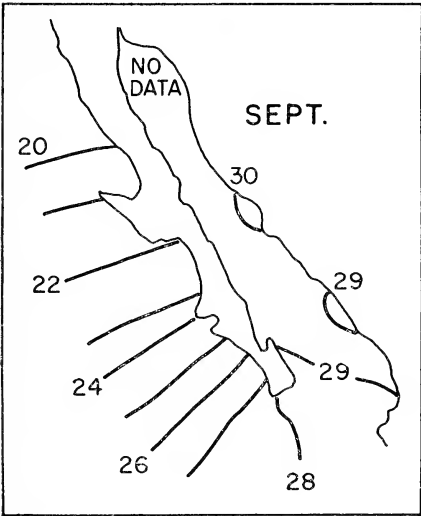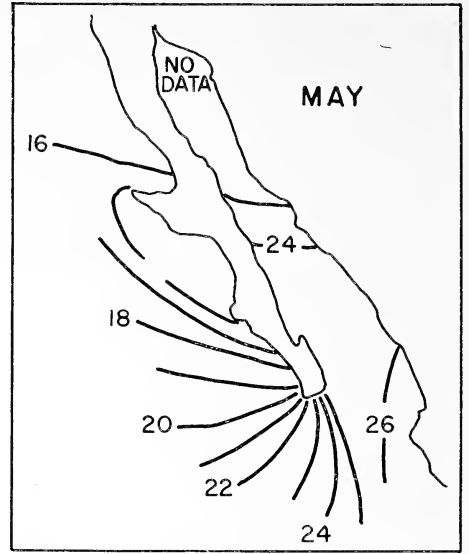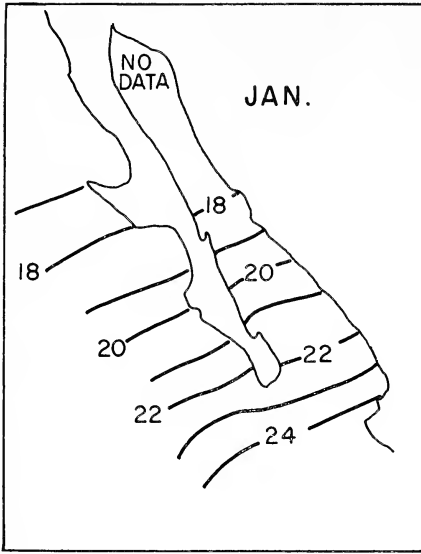
FIG. 4. Sea surface temperatures (°C.) in the Gulf of California. (After Thorade, 1909.)

aim was geological (Geol. Soc. Amer., Mem., 1950) but a few hydrographic stations were made (Fig. 2). Silicate and phosphate were measured for the first time in the Gulf, but the methods used in determining the concentrations do not warrant a detailed description of them. A brief account on the silicate distribution in the Gulf was given by Sverdrup (Sverdrup and staff, 1940). In 1944 the Mexican government sponsored a brief study of the Gulf in order to determine the feasibility of a minor guano industry (Osorio Tafall, 1944). The industry was never started. In 1956 the U. S. Fish and Wildlife Service has planned two expeditions into the Gulf to study the distribution of sardine eggs and larvae and to make frequent hydrographic stations, which undoubtedly will bring back new and valuable data for further scientific investigations.

CLIMATOLOGY

The great differences in climatic conditions observed in the Gulf as one proceeds from northwest to southeast, covering nearly nine degrees of latitude, and the differences that exist between the east side and the west side of the Gulf, are closely related to the atmospheric circulation and to the existence of mountain ranges that modify this circulation.

The influence of the Pacific Ocean upon the climate of the Gulf is greatly reduced by a nearly unbroken chain of mountains, 2000 to 3000 m. high, in Baja California. The considerable differences in temperatures and precipitation between the Pacific side and the Gulf side have already been mentioned by Thorade (1909) and are fully confirmed by data collected by the Servicio Meterologico Mexicano (Boletin Anual). Along the Pacific side of the peninsula the air temperatures are never excessively high and precipitation falls during the winter season in the northern part, and during the summer season in the southern part, with annual amounts around 200 mm. Along the Gulf side air temperatures are very high in summer and rather cool in winter. In

the north all the precipitation falls in summer. The amount of rainfall (Table 1) varies between traces in the north and 200 mm. at the southern tip of Baja California, which is crossed by the Tropic of Cancer. The rainfall on the corresponding latitude on the eastern side of the Gulf amounts to 400 mm. per year.

On the average the west coast of the Gulf receives only half as much rain as the east coast. In Sonora the winter is cool and the summer hot. Precipitation falls from July to September, varying between traces in the northernmost part and 251 mm. in Guaymas. In Sinaloa the winter is warm and the summer less hot than in Sonora. Precipitation falls from August to October, with amounts between 300 mm. in the north and 850 mm. in Mazatlán (Table 1). From the discussion of the precipitation figures it becomes evident that the Gulf of California is far from being situated in a desertlike environment.[2] The vegetation in Baja California and Sonora is of

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[2] Most Americans call northern Sonora and Baja California a desert, though people from North Africa and South America would consider this region a dry steppe.

TABLE 1

MEAN MONTHLY AIR TEMPERATURE AND PRECIPITATION 1921–1935 (SERV. MET. MEX., BOLETIN ANUAL)

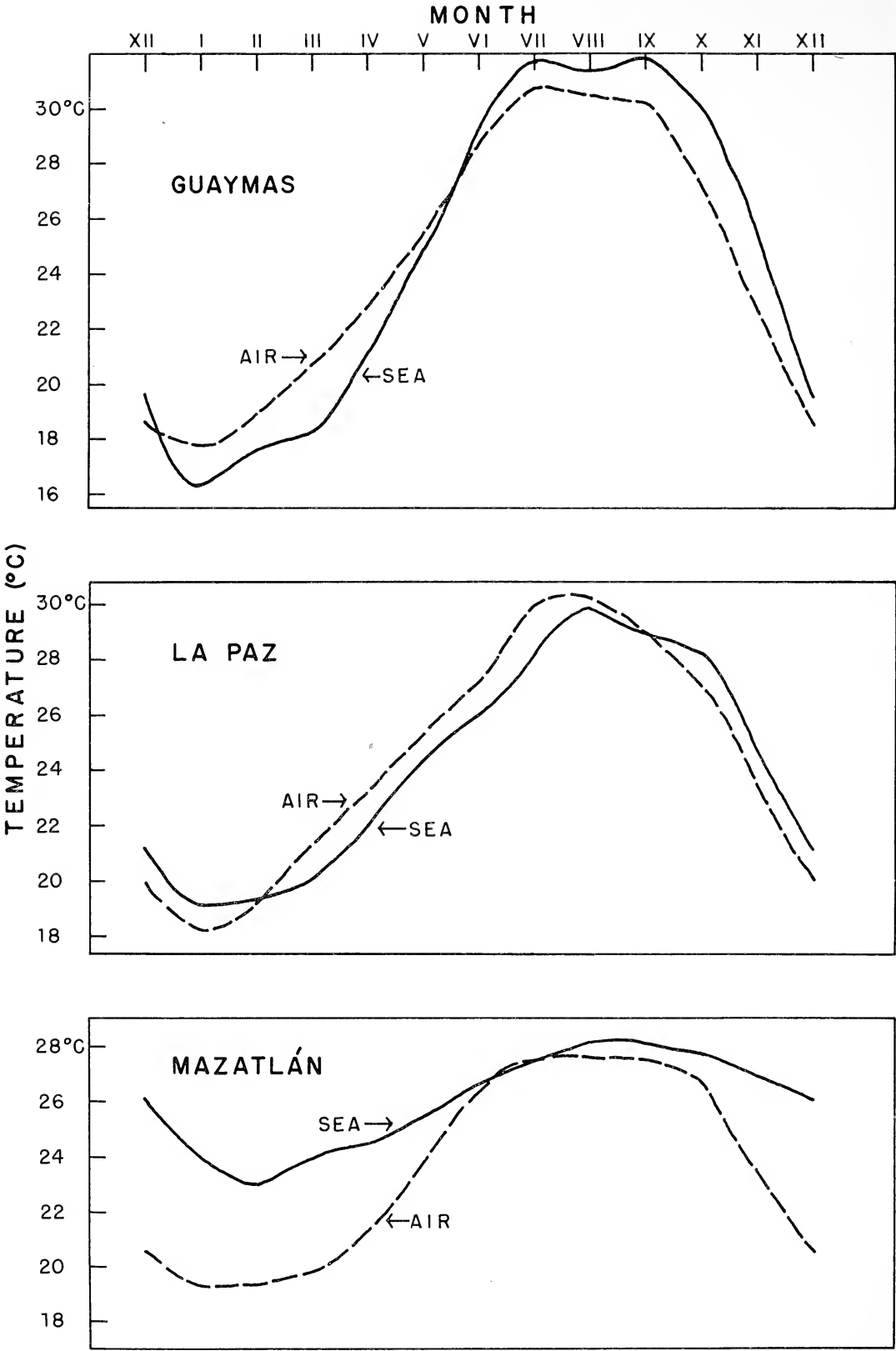|	WEST COAST (IN GULF)				EAST COAST (IN GULF)				EAST COAST (OUTSIDE GULF)		
	Mulege (26°53′N–112°00′W)		La Paz (24°10′N–110°18′W)		Guaymas (27°55′N–110°53′W)		Topolobampo (25°36′N–109°03′W)		Mazatlán (23°11′N–106°25′W)		Cabo Corrientes (20°24′N–105°43′W)
	Temp. °C.	Prec. mm.	Temp. °C.	Prec. mm.	Temp. °C.	Prec. mm.	Temp. °C.	Prec. mm.	Temp. °C.	Prec. mm.	Temp. °C.	Prec. mm.
January...	14.0	2.6	18.2	3.2	17.7	7.9	18.6	6.4	19.3	11.0	23.2	19.5
February..	16.0	3.4	19.2	11.4	18.9	6.3	19.7	6.6	19.4	9.7	22.9	29.6
March....	17.8	0.1	21.3	0.8	20.7	4.6	20.1	6.4	19.7	3.4	22.7	1.3
April......	20.1	0.2	23.2	0.2	22.8	3.0	22.2	tr.	21.3	0.1	23.9	tr.
May......	22.9	0.1	25.5	tr.	25.5	2.8	25.0	1.8	23.8	1.8	25.4	2.3
June......	27.2	tr.	27.2	0.2	28.8	0.7	29.1	5.3	26.4	29.2	26.7	57.3
July......	30.5	6.1	30.0	6.3	30.7	46.7	29.8	39.9	27.5	166.9	28.9	145.0
August....	30.4	16.8	30.3	41.7	30.5	75.5	29.7	100.6	27.6	241.8	27.9	272.1
September.	29.0	40.0	29.0	51.9	30.2	54.4	29.7	55.9	27.5	268.6	27.5	307.0
October...	24.6	5.4	27.0	9.6	27.3	9.5	27.8	73.7	26.7	61.6	27.5	91.0
November.	19.5	6.8	23.2	13.4	22.6	11.1	24.0	7.0	23.5	11.7	26.1	15.2
December.	14.9	19.2	20.0	34.3	18.6	28.9	19.7	55.3	20.6	44.4	23.8	13.5
Year......	22.2	101.1	24.4	173.0	24.5	251.4	24.6	358.9	23.6	850.2	25.5	953.8
Minimum.	0.0	—	0.0	—	7.0	—	8.0	—	11.2	—	12.0	—
Maximum.	41.9	—	40.5	—	47.0	—	41.1	—	33.4	—	43.8	—

FIG. 5. Air and sea surface temperatures in Guaymas, La Paz, and Mazatlán.

the dry steppe type, and in southern Sinaloa it is tropical.

The distribution of air temperatures (Fig. 5) shows a temperature minimum in January and February and a maximum in August and September. The annual range in temperatures increases from south to north and is somewhat greater along the coast of Baja California than along Sonora and Sinaloa. The mean annual range at the entrance is around 10°C. and in the northernmost part about 20°C. The extreme annual range (Table 1) is approximately twice the average annual range (Serv. Met. Mex., Boletin Anual). In general the air is warmer than the sea during the first half of the year and cooler during the second, except for Mazatlán, where the air is always cooler than the sea (Fig. 5).

The distribution of winds (Table 2) shows that the monthly average wind velocities are quite low, lying between 1.5 m/sec and 6.1 m/sec. The higher values are found in winter and spring. The direction of winds varies with season and with distance from the entrance. During winter, northerly winds are predominant in the entire Gulf, but in summer the southern half of the Gulf is mostly influenced by southerly winds. In the northern half, southerly winds blow only one or two months of a year.

Winter gales of short duration, locally known as chubascos, are frequent and velocities may occasionally reach 30 m/sec.

Hurricanes are not as rare in the Gulf as is generally believed. Between 1910 and 1930 thirty-nine were registered (Schott, 1935: 280). These hurricanes, known as "El Cordonazo," may enter the Gulf any time between May and November, but are most frequent in September and October (Fig. 6).
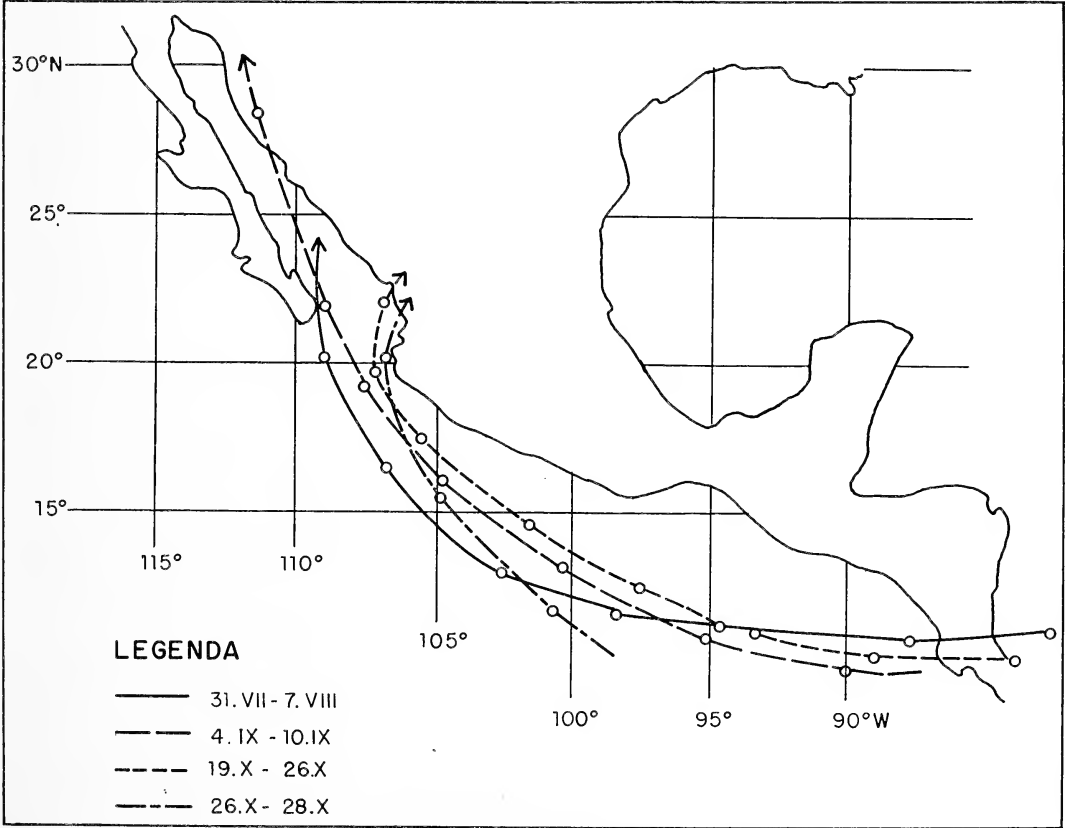

FIG. 6. Paths of hurricanes in 1936. (After Serv. Met. Mex., Boletin Anual, 1936.)

TABLE 2
MEAN MONTHLY WIND VELOCITY IN LA PAZ,
GUAYMAS, AND MAZATLÁN
(Serv. Met. Mex., Boletin Anual)

	LA PAZ	GUAYMAS	MAZATLÁN
	m/sec	m/sec	m/sec
January.......	2.6	4.8	6.1
February......	2.4	4.2	5.9
March........	2.2	5.3	5.5
April.........	2.3	5.1	5.0
May..........	2.1	4.6	4.8
June..........	2.4	4.3	4.6
July..........	2.0	3.5	4.3
August.......	2.0	3.6	4.9
September.....	1.5	4.4	5.0
October.......	1.8	4.8	5.1
November.....	2.3	4.6	4.1
December.....	2.3	4.9	5.5
Year..........	2.2	4.5	5.1

In La Paz winds are northerly from November until March and southerly from April until October.

In Guaymas winds are northerly from August until May and southerly in June and July only.

In Mazatlán winds are northerly from November until April and westerly from May until October.

They originate in the Caribbean Sea or off the coast of Central America and it takes them between five to seven days to reach the Gulf (Serv. Met. Mex., Boletin Anual).

If one compares the distribution of winds and the occurrence of the rainy season with the migrating low pressure system over western Mexico (Fig. 7) it is seen that northerly winds are found with the low pressure to the east, and southerly winds with the low pressure to the northwest. The beginning of the rainy season is connected with the appearance of southerly winds that carry moist air into the Gulf and give rise to uplift rain.

Evaporation is one of the most important factors in the Gulf and is responsible for the high salinity observed in the surface layers. The amount of evaporation has been determined from pan observations at a few shore stations (Serv. Met. Mex., Boletin Anual). These measurements show a main maximum in summer and a main minimum in winter. The amount of annual evaporation varies between 1800 mm. in La Paz and about 3000 mm. in Guaymas (Table 3). The values are consistent from year to year for each station and the deviations from the above values are generally less than 10 per cent (Serv. Met. Mex., Boletin Anual).

Since evaporation from pans is not strictly representative for evaporation from the sea surface, it is of interest to see how the observed evaporation from pans compares to evaporation derived from indirect methods.

The use of the energy budget method is restricted, because the advection term cannot be evaluated.

In the meteorological approach a straight line relationship between the evaporation, E, and the product of wind velocity, W, and vapor pressure difference, Δe, is assumed (Jacobs, 1951); the coeficient of proportionality depends upon the height where the wind velocity and the humidity has been measured, and upon the roughness of the sea surface. In the following the coeficient of proportionality will be taken as 4.26 (Jacobs, 1951) so that

$$E = 4.26 \, W\Delta e$$

where E is in mm/month, W in m/sec, and Δe is in mb.

A comparison between the pan and computed evaporation for the year 1938 is shown in Table 3, and it is readily seen that notable differences exist. The computed evaporation is less than the observed evaporation (Fig. 8) for La Paz and Mazatlán. In La Paz the maximum evaporation occurs in summer and the minimum in winter; in Mazatlán the observed evaporation shows a winter minimum and a summer maximum, whereas the computed evaporation has a summer minimum and a fall maximum. The summer minimum is due to the low wind velocities observed during this season. Values for Guaymas are not strictly comparable because the pan observations were made on a nearby station farther inland; nevertheless it is interesting to note that there the total annual amount of evaporation is considerably higher than in La Paz or Mazatlán.
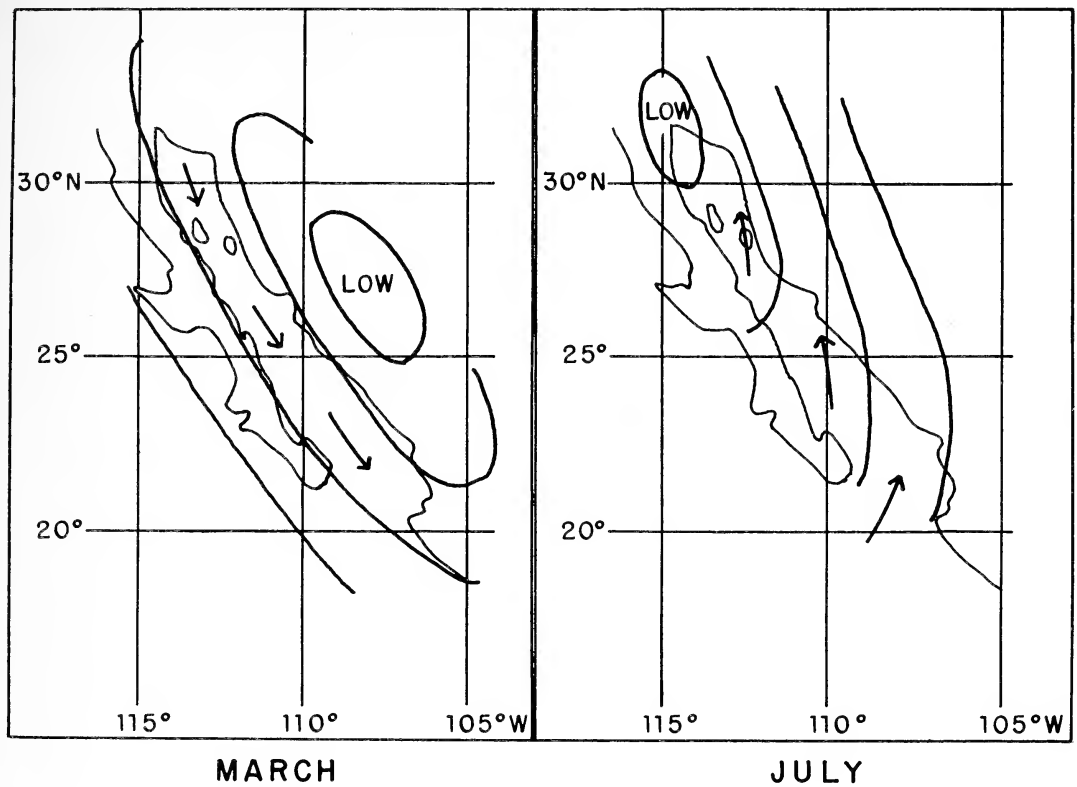
FIG. 7. Position of the low pressure in March and July, and resulting winds.

TABLE 3
MEAN MONTHLY EVAPORATION
E_p = measured from pans, E_c = computed

|	LA PAZ (1938)		GUAYMAS (1943)		MAZATLÁN (1938)	
	E_p	E_c	E_p	E_c	E_p	E_c
	mm.	mm.	mm.	mm.	mm.	mm.
January...............	139	76	139	174	185	172
February.............	120	41	206	216	213	194
March................	129	81	286	269	148	129
April.................	119	98	351	276	205	133
May..................	146	127	446	337	210	163
June.................	166	126	420	299	211	130
July.................	174	172	294	280	230	123
August..............	197	156	246	239	289	181
September...........	150	82	198	266	202	190
October.............	159	180	162	337	210	245
November...........	158	98	148	178	162	196
December...........	154	57	92	288	140	196
Year.................	1809	1294	2958	3247	2492	2071
(E_c/E_p)year...........	0.72		(1.10)		0.83	
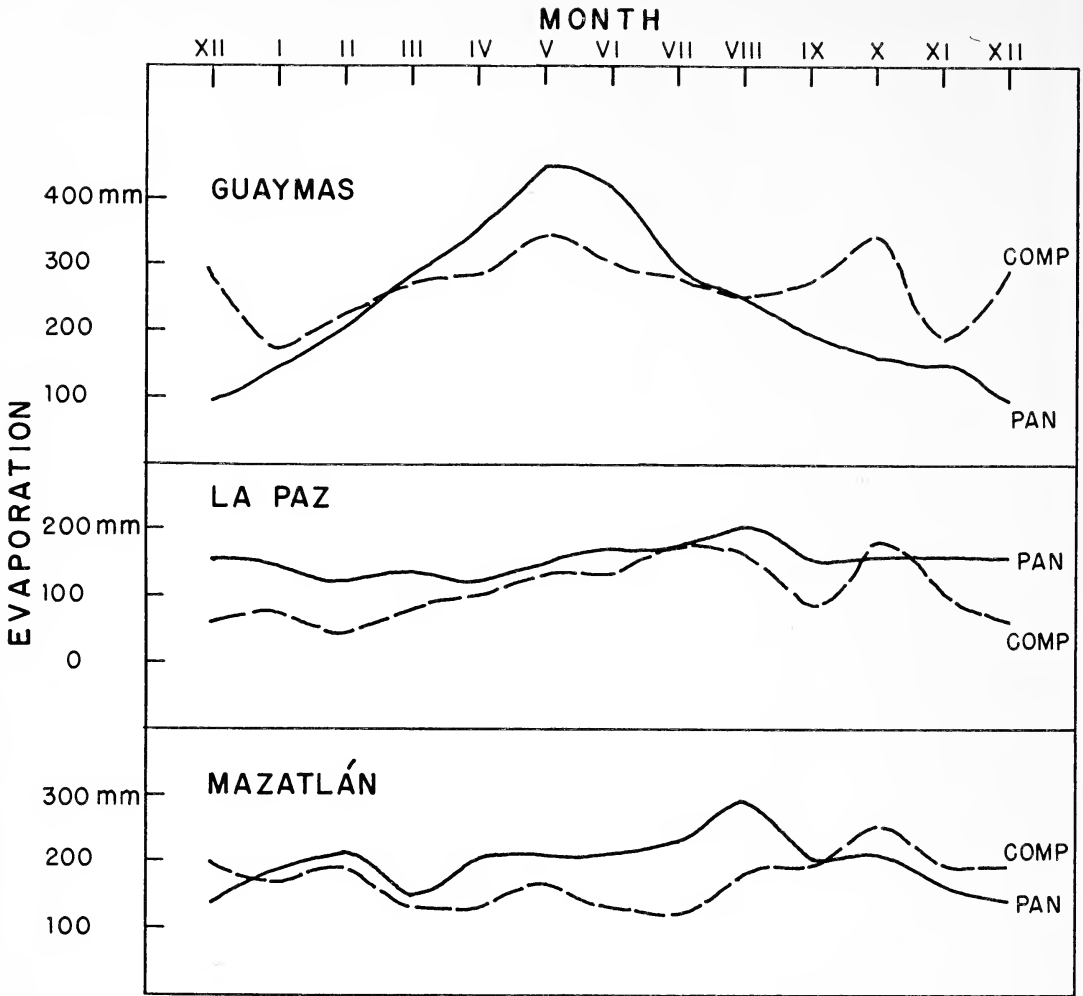
FIG. 8. Computed evaporation (E_e) and pan evaporation (E_p).

The difference, evaporation minus precipitation, has a maximum in early summer, a minimum during the rainy season, and a secondary maximum immediately after the rainy season. Except for Mazatlán during the peak of the rainy season, evaporation exceeds precipitation during all months of the year. The few available data indicate that the mean annual evaporation for the southern half of the Gulf lies between 1500 and 3000 mm. For the entire Gulf, considering the dry northern part, roughly 2500 mm. can be taken as a conservative estimate for the mean yearly evaporation. With this value the rate of evaporation over the entire surface of the Gulf becomes 5.25 x $10^{11} m^3$/year or 1.7 x $10^4 m^3$/sec.

GENERAL CIRCULATION

The bulk of water in and near the Gulf of California is the same as in the equatorial Pacific, slightly modified at the surface by extensive evaporation and by the admixture with water brought south by the California Current. The influence of the latter is restricted to the vicinity of Cabo San Lucas.

The great similarity between the Gulf and Pacific Equatorial water, below the thermocline, is illustrated by the close agreement

between the temperature-salinity relationships for either water mass (Fig. 9). Points for the Gulf were obtained from the "E. W. Scripps" expedition in 1939 (Sverdrup and staff, 1943). The solid curves represent the limits for typical Gulf water, the dashed curves show the limits for the equatorial Pacific (Sverdrup et al., 1942: 741).

It is seen that a nearly straight line relationship exists between the points 16°C., 35.2%₀ and 9°C., 34.6%₀. The salinity minimum lies in both cases between 34.5 and 34.6%₀ and has a corresponding temperature of between 5°C. and 7°C.

The circulation in the Gulf is rather complicated and not fully understood. In winter (Fig. 10) outflow takes place at the surface and inflow at greater depths, in summer (Fig. 11) the situation is reversed. Thorade (1909) mentioned one case of oppositely running currents at the surface and at 40 m. near the coast of central Baja California.

In the northern part of the Gulf cooling of high saline water in winter leads to the formation of a bottom water mass (Sverdrup, 1941), which is characterized by a temperature above 10°C. and a salinity above 34.9%₀ and a relatively high oxygen content. This water fills the isolated basins of the northern shelf

and moves southward along the coast of Baja California (Fig. 19).

Tidal currents are strong in the northern third of the Gulf and may obtain velocities of several knots in the narrows between the islands and near the mouth of Rio Colorado.

The exchange between the Gulf and the Pacific Ocean cannot be calculated accurately from the available data. It is, however, possible to get a rough estimate of the exchange of water and salt across latitude 23°N assuming conservation of these properties. If E denotes the rate of evaporation and if S_i, S_0 and Q_i, Q_0 represent the salinity and amount of the in- and outflowing water, respectively, the following equations hold (Sverdrup et al., 1942: 148)

$$Q_i = \frac{S_0}{S_0 - S_i} E \qquad Q_0 = \frac{S_i}{S_0 - S_i} E.$$

Taking E as 1.7×10^4 m³/sec (see above), S_i as 34.6%₀ and S_0 as 35.1%₀ one gets:

$$Q_i = 1.19 \times 10^6 \text{ (m}^3/\text{sec)}$$
$$Q_0 = 1.17 \times 10^6 \text{ (m}^3/\text{sec)}.$$

It is seen that evaporation plays only a negligible part in the general circulation of the Gulf, and that inflow very nearly balances outflow. If one assumes that the outflowing
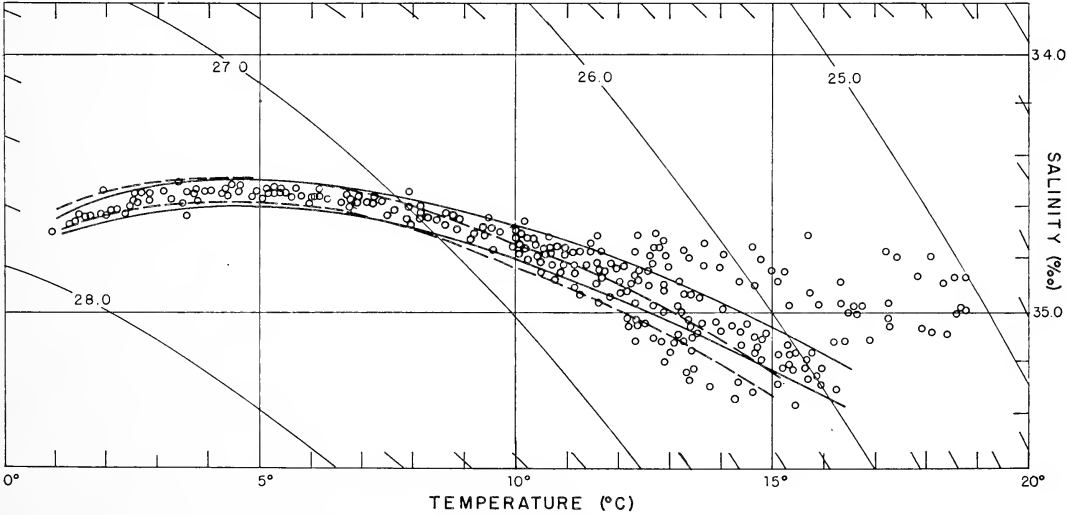

FIG. 9. Temperature-salinity diagram for the Gulf (solid lines) and for the equatorial Pacific (dashed lines).
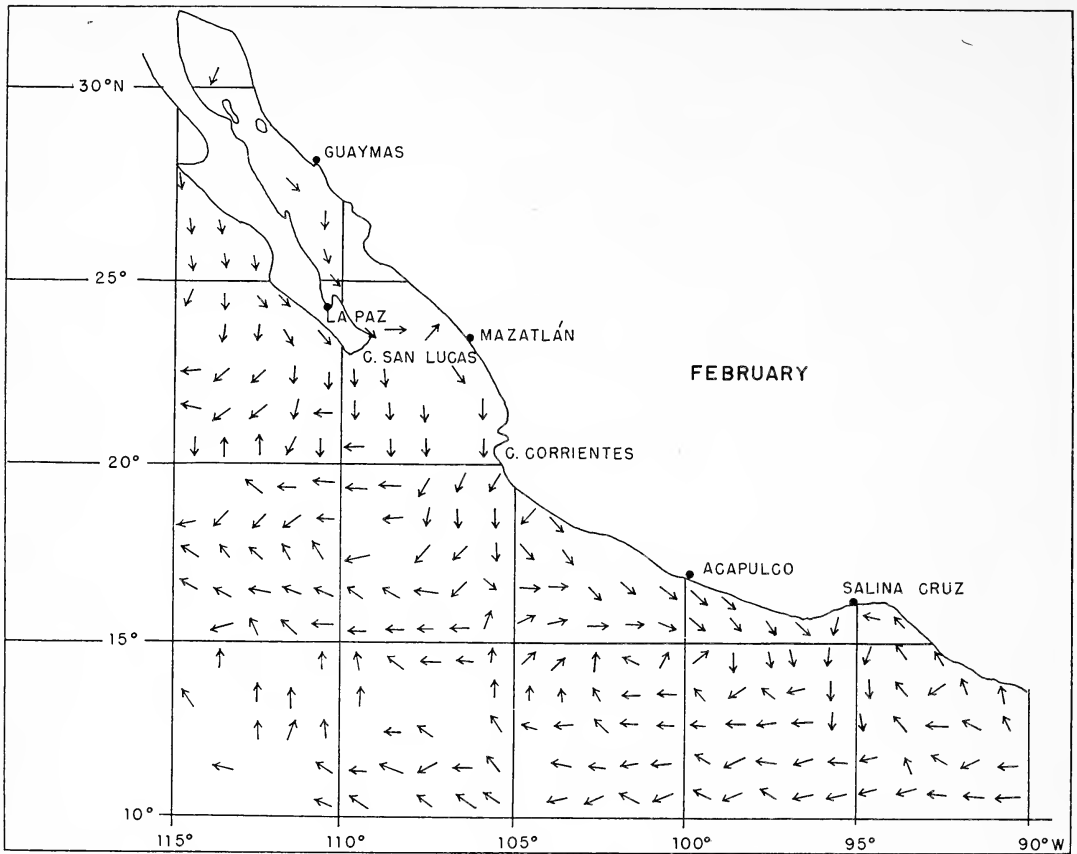
FIG. 10. Surface currents in February. (After U. S. Hydrog. Off., 1947.)

water extends over a depth range of 50 m. and inflowing over 1500 m., across latitude 23°N, the velocity of the outflowing water is 7 cm/sec and of the inflowing water 0.3 cm/sec. This calculation holds only for winter, when northerly winds are responsible for outflow at the surface.

The influence of the Gulf of California upon the adjacent Pacific Ocean is small (Sverdrup et al., 1942: 732) and varies with season. The influence is greatest in winter when strong northerly winds drive the surface layers out of the Gulf and least in summer when southerly winds drive oceanic water into the Gulf. The exact distance seaward from the entrance of the Gulf that Gulf water can be detected (by its higher salinity) is not known.

The circulation in the vicinity of the Gulf of California is affected by the water carried

south by the California Current and by the water found off Mexico and Central America. The former is characterized by a low temperature, a low salinity, and a rather high oxygen content, whereas the latter has a very high temperature at the surface and a very low oxygen content below the thermocline (Sverdrup et al., 1942: 730). Between both lies a transition region which, 500 miles to the west, is found approximately between latitudes 17°N and 20°N (Wooster and Cromwell, verbal communication).

In February (Fig. 10) the coastal surface circulation (U. S. Hydrog. Off., 1947) is characterized by southward currents north of about latitude 20°N and by westward flowing currents south of this latitude. An interesting feature is a large gyre off the southern coast of Mexico which is maintained by strong
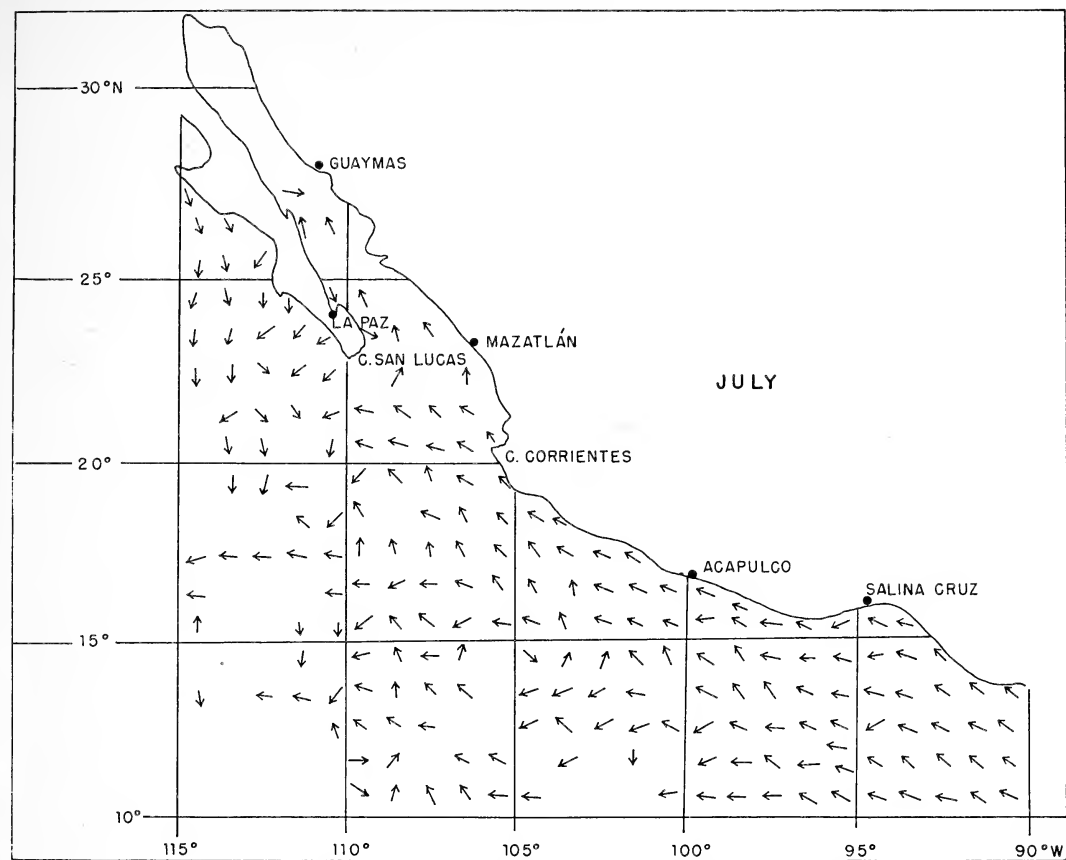
FIG. 11. Surface currents in July. (After U. S. Hydrog. Off., 1947.)

northerly winds blowing into the Gulf of Tehuantepec. This gyre is strictly a winter phenomenon and ceases as soon as the winds in the Gulf of Tehuantepec change their direction.

In July (Fig. 11) a current flows north along the coast of Mexico and enters the Gulf of California. The entire current pattern east of 110°W is characterized by a slowly west to northwest moving water mass. West of this longitude the current is toward the south north of latitude 20°N and toward the west south of this latitude.

The monthly average speeds of these currents are low and lie almost entirely within 5 cm/sec and 20 cm/sec.

FRONTS IN THE VICINITY OF THE GULF

In the following the term "front" will be used as suggested by Cromwell and Reid (1956), i.e., as a narrow band along the sea surface across which the density changes abruptly. The terms "temperature front" and "salinity front" will be used to describe the density front, since it is only from temperature and salinity measurements that the density can be adequately determined. The definite character of a front can only be established if continuous temperature and salinity records are available. Unfortunately there are no continuous records of salinity, for which reason a description of the fronts in the vicinity of the Gulf must be based on closely ‑paced stations rather than upon continuous records.

Two regions of rapid temperature and salinity transition have been found to exist in the Gulf Entrance, one off Cabo San Lucas and one off Cabo Corrientes (Fig. 12). The San

Lucas transition represents a very sharp boundary between warm and high-saline Gulf water, and cool, low-saline water from the California region. It was first described by Thorade (1909), who pointed out that the intensity of the front is seasonal in character and that the maximum intensity occurs in late spring when the temperature differences between the Gulf and California Current water are greatest.

The San Lucas front is illustrated in Figure 13 (unpublished data). It is seen that the front is marked by a narrow band across which the temperature decreases from 21° to 18°C. and the salinity from 34.6 to 34.1°/oo.

It is possible that when the more saline Gulf water is cooled rapidly some sinking of this water takes place at the front, but this

feature has not been investigated. The temperature structure below the San Lucas front is shown in Figure 14. The bathythermograph section from Cabo Corrientes to Cabo San Lucas was prepared from hourly temperature observations made aboard the U. S. vessel "Golden Bear" and led to the discovery of another front in the vicinity of Cabo Corrientes. It is seen that the temperature differences across the front increase with increasing depth. The increase could be explained as the result of decreased mixing at greater depth, but the feature needs further investigation.

Since the winds were northerly in April, 1949, when the "Golden Bear" crossed the Gulf Entrance it can be assumed that an already warmed water mass was driven out of the Gulf and pushed the cooler water north
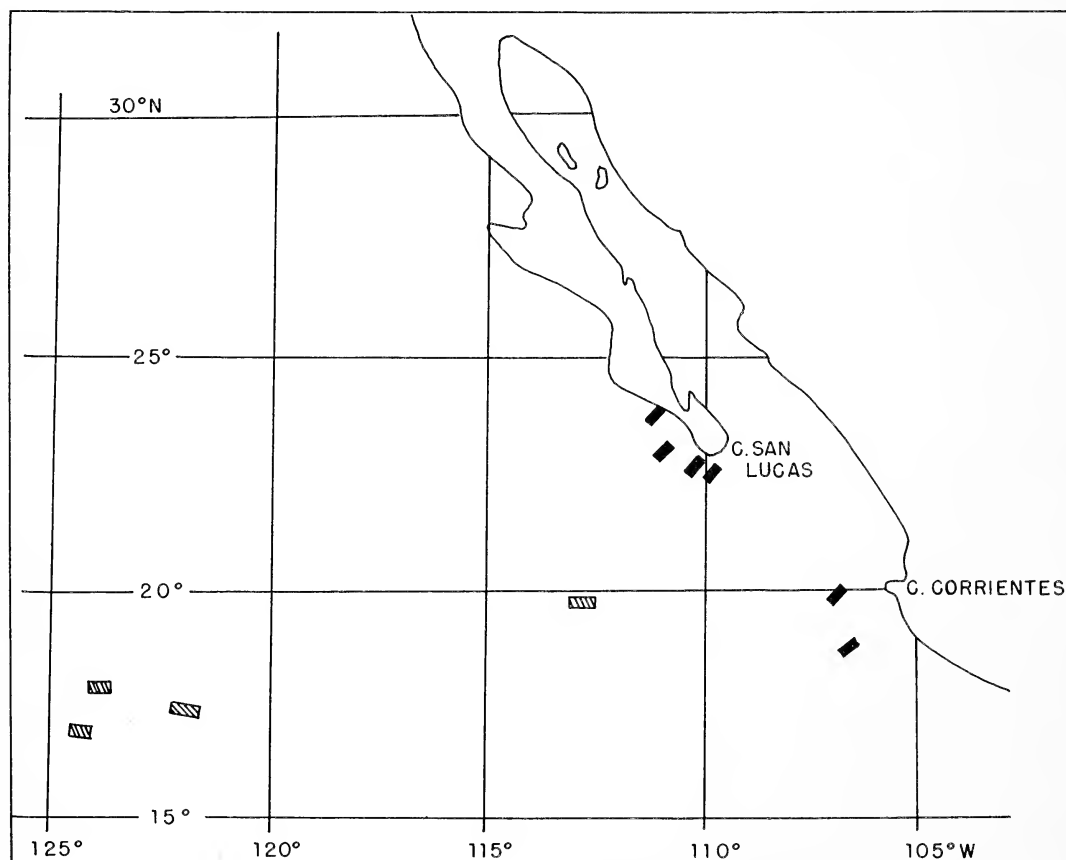

FIG. 12. Observed fronts (solid black) and transition regions (shaded) near the Gulf of California.
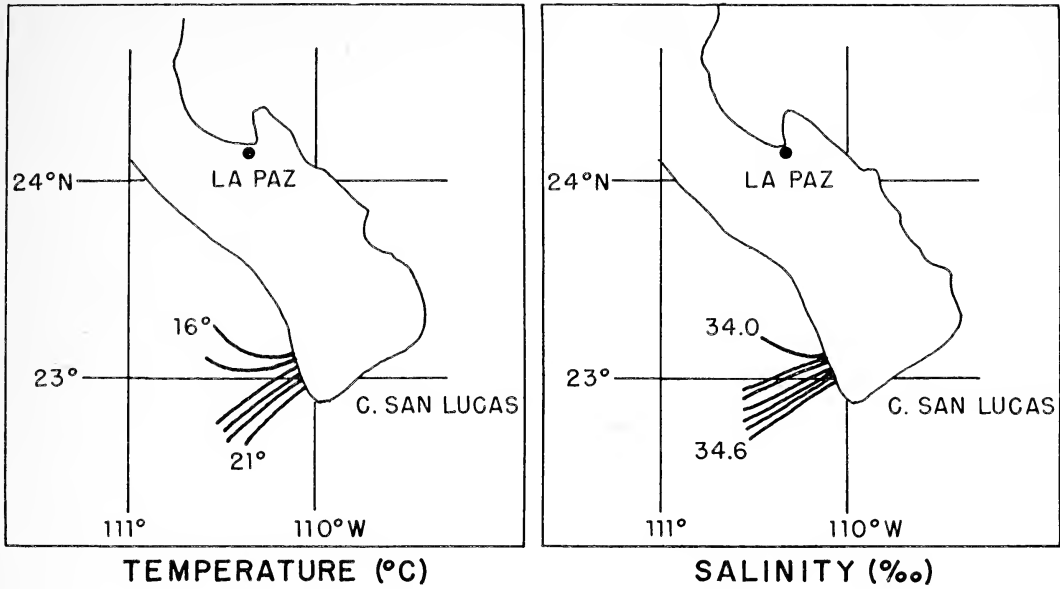
FIG. 13. Surface appearance of the San Lucas front.

of Cabo San Lucas and south of Cabo Corrientes aside, thus giving rise to the fronts observed.

UPWELLING

Upwelling in the Gulf can be expected along the east coast with northerly winds and along the west coast with southerly winds. So far only upwelling along the east coast

has been investigated (Allen, 1937).

The upwelled water is characterized by a low temperature and a low salinity when compared to the temperature and salinity of the surroundings. The surface oxygen content of the water is not necessarily a good indicator of upwelling, since it is strongly influenced by phytoplankton productivity, and by exchange with the atmosphere.
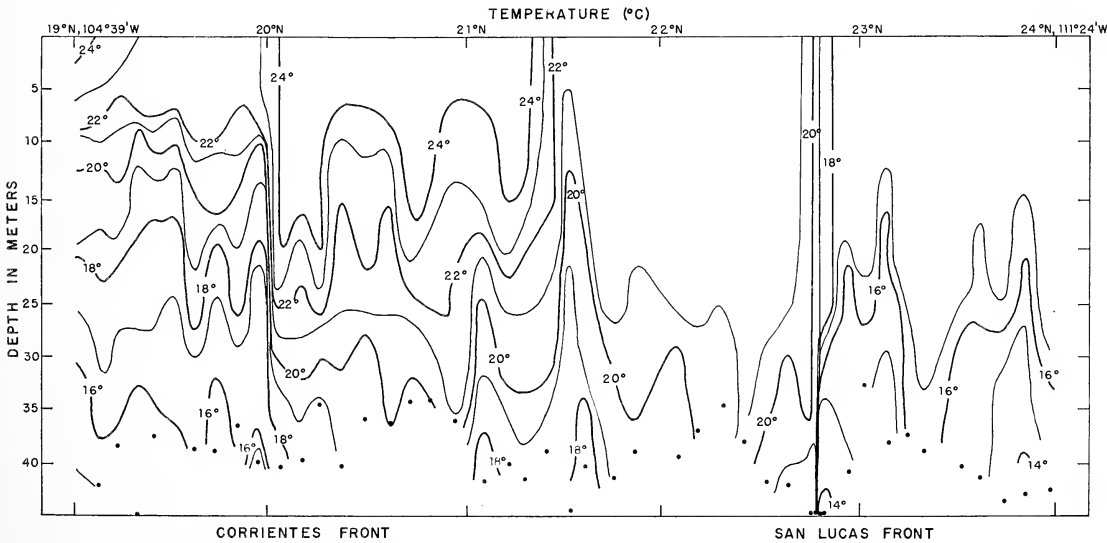

FIG. 14. Bathythermograph section from Cabo Corrientes to Cabo San Lucas, April, 1949.

Upwelling is not uniformly distributed along the east coast with northerly winds but seems rather to be confined to certain places. Such places are in the lee of Isla Tiburón, in Bahia Guaymas, in Bahia Yavaros and in the vicinity of Topolobampo (Allen, 1937). It is interesting to note that all these places are in the lee of islands or headlands, which suggests that upwelling is largely controlled by the irregularities of the coast line as well as by the winds.

Upwelling is important in the Gulf as a means of replenishing the depleted surface layers with plant nutrients from below. There are, unfortunately, no data on the concentration of plant nutrients available for the regions where upwelling occurs, and it is for the time being not possible to investigate the biological role of upwelling in a quantitative manner. The high concentration of phytoplankton in the upwelling areas in spring (Allen, 1937) is indicative, however, of a sufficient concentration in plant nutrients to support the large standing crop.

It should be pointed out that upwelling is not the only process to fertilize the surface layers with plant nutrients. Increased wind mixing and winter convection may be of equal importance. The latter process is effec-tive in the northernmost part of the Gulf (Sverdrup, 1941) whereas the former is bene-ficial everywhere.

SEASONAL VARIATION OF TEMPERATURE AND SALINITY IN THE GULF

Information on the monthly variation of temperature and salinity at the sea surface in the Gulf is very scanty.

The first attempt to draw charts of monthly average sea surface temperatures was made by Thorade (1909). He collected data from ships' observations for many years and averaged them. These pre-World War I charts are still the only ones in existence (Fig. 3). Since the Second World War the U. S. Coast and Geodetic Survey has published sea surface temperatures from a few shore stations in the Gulf. These are given in Table 4. It is seen that the minimum temperatures occur in January and February and the maximum temperatures in August and September. The mean annual range lies between 23°C. and 28°C. in Mazatlán and between 16°C. and 32°C. in Guaymas. In the northern half of the Gulf the mean monthly temperatures are not known. The minimum in the northernmost part seems to be above 10°C. since this is the temperature of the bottom water found there (Sverdrup, 1941).

TABLE 4

MONTHLY VARIATION OF SEA WATER TEMPERATURE AND SALINITY FOR LA PAZ, GUAYMAS, AND MAZATLÁN
(USCGS 1951, Schott, 1935)

	LA PAZ		GUAYMAS		MAZATLÁN	
	t°C.	S°/oo	t°C.	S°/oo	t°C.	S°/oo
January	19.1	35.5	16.3	36.2	24.0	34.8
February	19.3	35.8	17.6	36.0	23.0	34.9
March	20.0	36.4	18.2	35.8	24.0	35.0
April	22.0	36.6	21.0	36.2	24.5	35.1
May	24.4	36.6	24.8	36.4	25.5	35.5
June	26.0	36.4	29.3	37.0	26.7	35.8
July	28.2	36.6	31.7	37.1	27.5	34.8
August	29.8	36.2	31.4	36.3	28.2	34.6
September	29.0	36.2	31.9	36.3	28.0	32.8
October	28.3	36.2	30.0	36.7	27.8	34.5
November	24.7	35.9	25.4	36.2	26.9	35.1
December	21.2	35.7	19.6	36.2	26.1	35.0
Year	24.3	36.2	24.8	36.3	26.0	34.9
Minimum	17.8	34.1	11.0	31.4	—	11.1
Maximum	33.3	40.4	36.2	41.0	—	36.7

The mean annual surface temperature is quite high in the Gulf and lies around 24°C. (Table 4). In Mazatlán the mean annual temperature is very high (26.0) and the surface water there is probably of advective origin, because it is always warmer than the air above it (Fig. 5).

Mean monthly salinities (USCGS 1951) are listed in Table 4. The salinity (Fig. 15) has two maxima and two minima. The first maxi-

mum is found around June and is the result of excessive evaporation. With the coming of the rainy season the salinity of the surface water falls and reaches a minimum at the peak of the rainy season. In October increasing winds and rapidly decreasing air temperatures and the lack of large precipitation give rise to a second peak in net evaporation which is also reflected in the second salinity maximum. After the October maximum the salinity de-
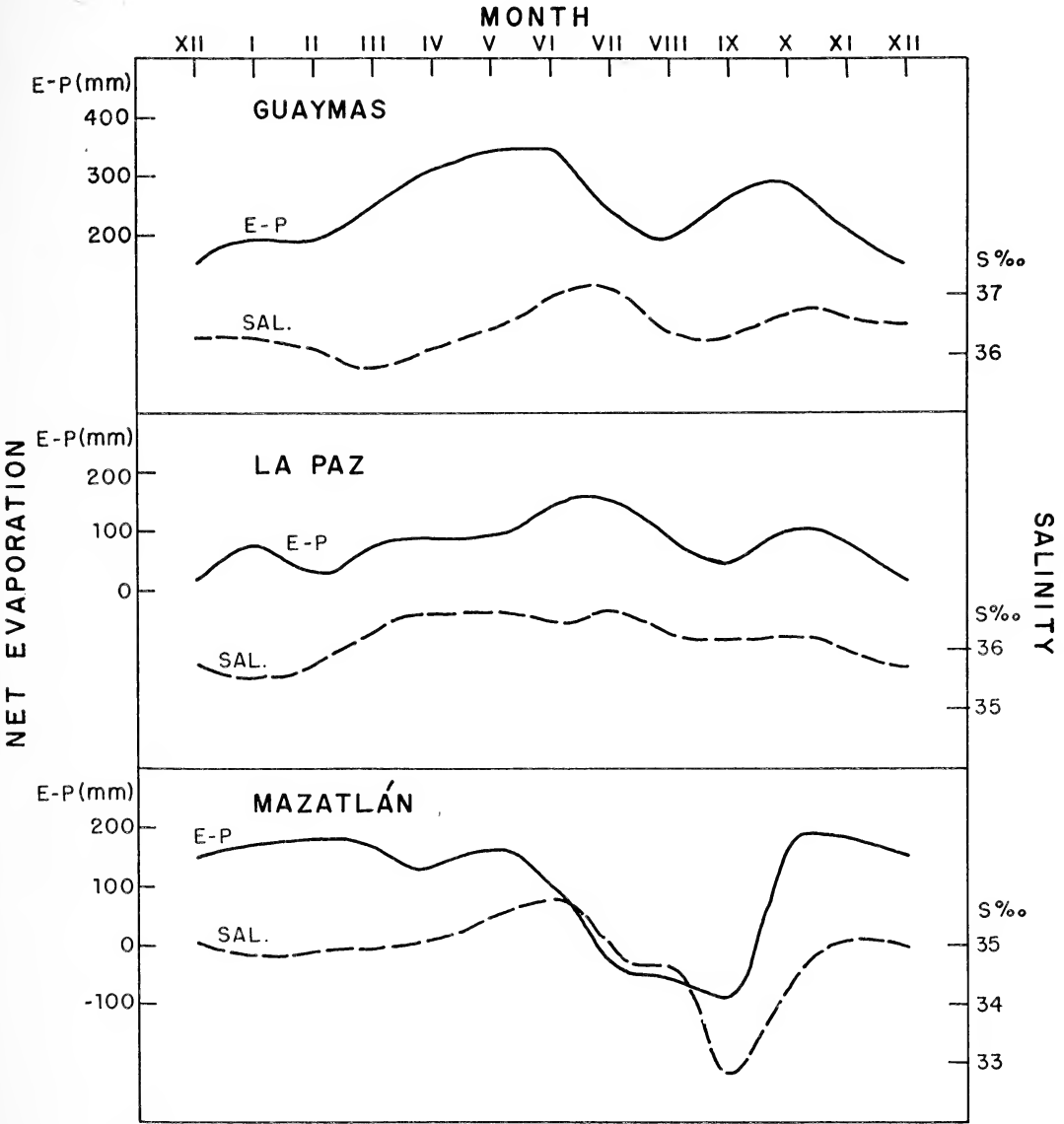

FIG. 15. Net evaporation and salinity for Guaymas, La Paz, and Mazatlán.

creases and reaches a second minimum around December. The salinity ranges between 35.5 and 36.5°/oo in La Paz and between 35.8 and 37.1°/oo in Guaymas. Both places are situated at the head of shallow bays where evaporation is extensive. These values are, therefore, not representative for the open Gulf.

In Mazatlán the salinity varies between 32.8 and 35.8°/oo. The very low value found in September (32.8°/oo) is possibly caused by extensive runoff from Rio Presidio during the rainy season.

Figure 15 illustrates that there is a very good agreement between net evaporation and salinity. The slight differences seen can be attributed to the different years in which the salinity was observed and for which the net evaporation was computed.

DISTRIBUTION OF PHYSICAL AND CHEMICAL PROPERTIES IN THE GULF

A preliminary discussion of the distribution of temperature, salinity, and oxygen in February and March, 1939, was published by Sverdrup (1941). A short report on the distribution of silicate and phosphate from October to December, 1940, was given by the same author (Sverdrup and staff, 1940). Here only a few conclusions will be drawn from the distribution of these properties. The distribution of phosphate and silicate in the Gulf can be discussed only qualitatively, because the measured data are such that they do not warrant a quantitative discussion.

Vertical Distribution

The Gulf can be divided vertically into a shallow upper layer (20 to 40 m. deep) where the distribution of properties is rather uniform due to wind stirring; a layer between roughly 50 and 150 m., varying with season, where the temperature, salinity and oxygen content decrease rapidly; and a deep layer, between the thermocline and the bottom, where the concentrations remain fairly constant from one season to another.

In the upper layer the concentrations vary considerably with time due to the amount of heating, cooling, stirring, evaporation, precipitation, runoff and various biological activities. Shallow and semi-enclosed bays show greater variations than the open Gulf. The layer of rapid density increase is generally closer to the surface during the warm season than during the cold season, but the available data are too few to give accurate depth ranges. Below the layer of rapid density increase the temperature decreases more or less slowly toward the bottom, but in a few deep basins, below 2000 m., a slight increase is observed due to the adiabatic effect.

The salinity shows a minimum (34.48–34.54°/oo) between 600 and 800 m. and increases slightly toward the bottom.

The amount of dissolved oxygen has a very pronounced minimum (less than 0.1 ml/l) between 300 and 700 m. and increases again toward the bottom.

The silicate content increases with depth and equals about 160 μg–at/l in the central part of the Gulf where the bottom deposits are largely diatomaceous oozes.

Horizontal Distribution

The horizontal distributions of temperature, salinity and oxygen in February and March, 1939, are illustrated in Figures 16, 17, 18 and 19.

At the surface (Figs. 16 and 17) the distribution of these properties is very complicated. The high oxygen values (more than 50 per cent supersaturated in places) are probably the result of extensive phytoplankton production. The southern half of the Gulf is slightly undersaturated with respect to oxygen. Upwelling as indicated by a low temperature (and salinity) can be seen to occur in Bahia Guaymas and Topolobampo.

At subsurface depths (Figs. 18 and 19) the two outstanding features are a tongue of warm, high saline and oxygen-rich water moving to the south along the coast of Baja California and a tongue of low saline, cool
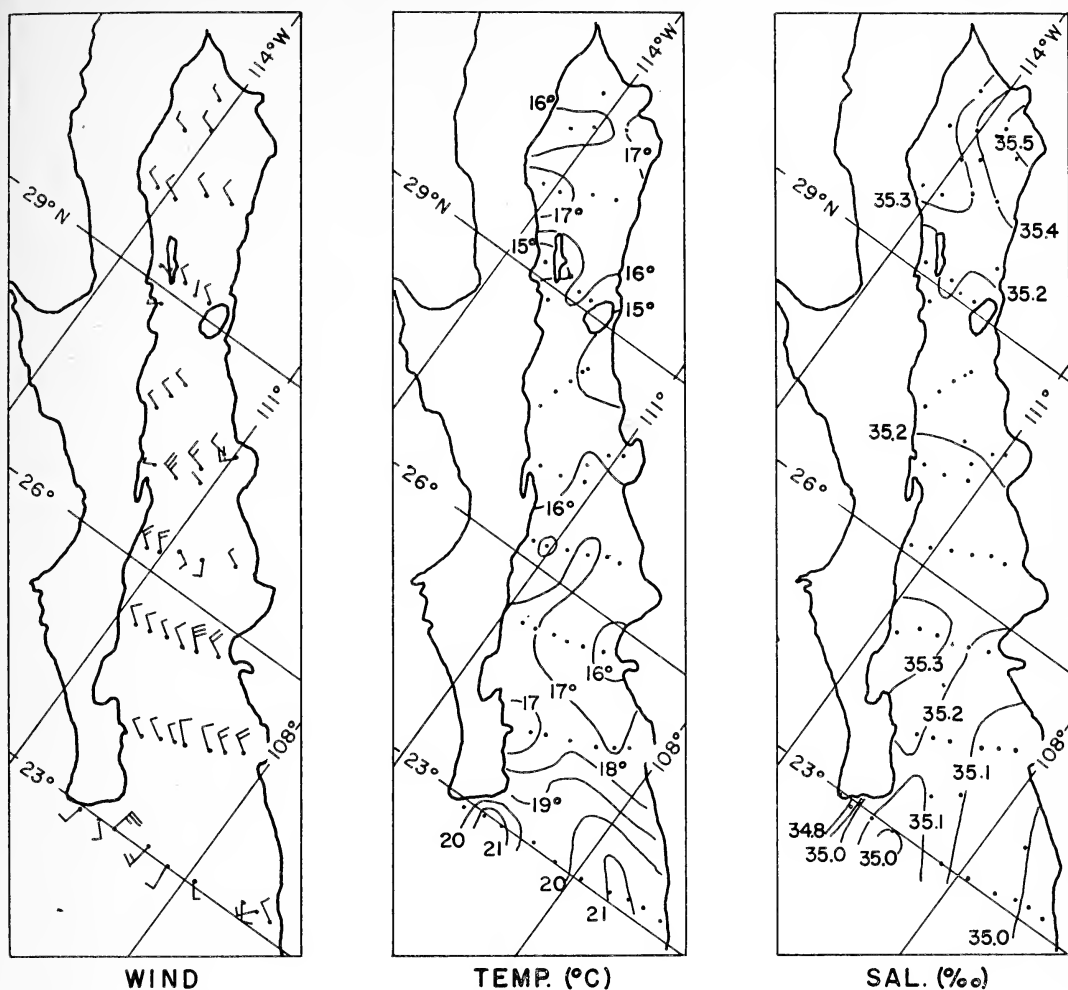
FIG. 16. Distribution of wind temperature and salinity at the sea surface in February and March, 1939.

and oxygen-poor water entering the Gulf from the south. The tongue along Baja California has possibly its origin in the northern part of the Gulf, because it is of nearly the same temperature, salinity and oxygen as the water of the northern area. The inflowing water mass shows the same characteritsics as the equatorial Pacific water (Fig. 9) and represents a compensation flow to replace the water lost by evaporation and wind drift out of the Gulf.

CONCLUSIONS

The Gulf of California remains oceanographically unknown to a great extent. The results that have been presented here are based on meager data and conclusions drawn from such data may have to be modified when more accurate and more complete data are available.

Conditions in the Gulf are dependent upon the conditions in the atmosphere and any changes that take place in the atmosphere will also be reflected in the Gulf. The submarine topography and the orientation of the shoreline also influence the circulation and hence the distribution of properties.

The bulk of the water found in the Gulf shows properties very similar to the Pacific Equatorial water mass. This water mass upon entering the Gulf is modified at the surface by extensive evaporation which increases its
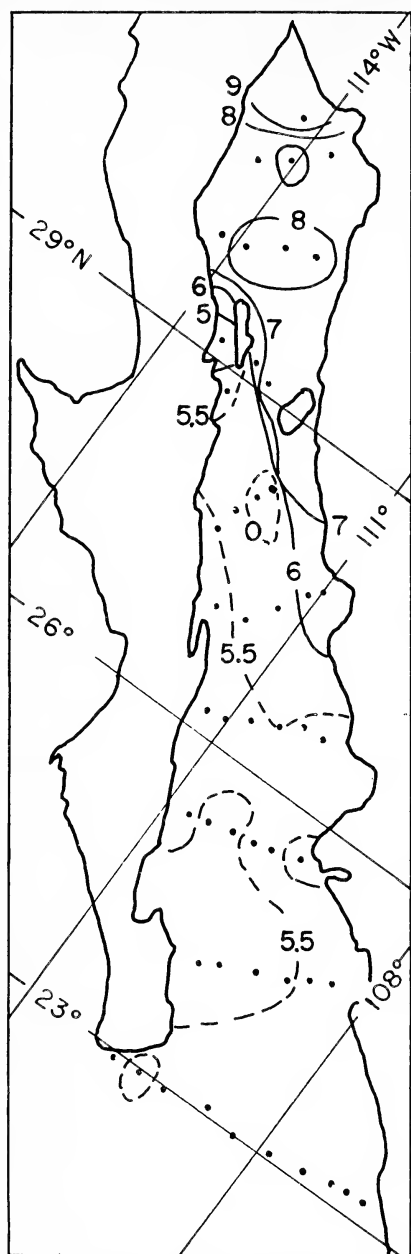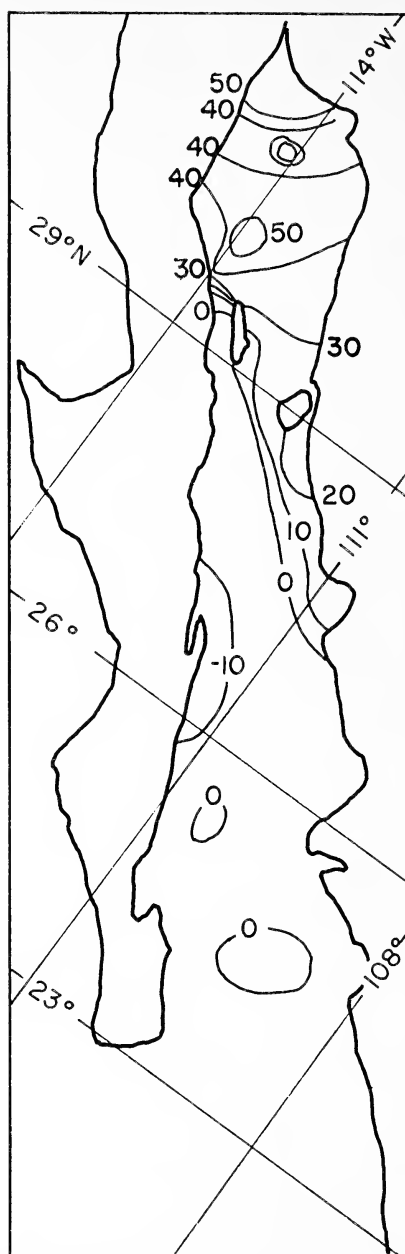
FIG. 17. Distribution of oxygen and oxygen saturation anomaly at the sea surface, in February and March, 1939.

salinity. The effect of evaporation increases as one proceeds toward the northwest.

The circulation in the surface layers is predominantly wind driven. Since the winds transport water of different origin towards the

entrance of the Gulf, it is a transition region marked by the existence of fronts of which the San Lucas front is the best developed and best known.

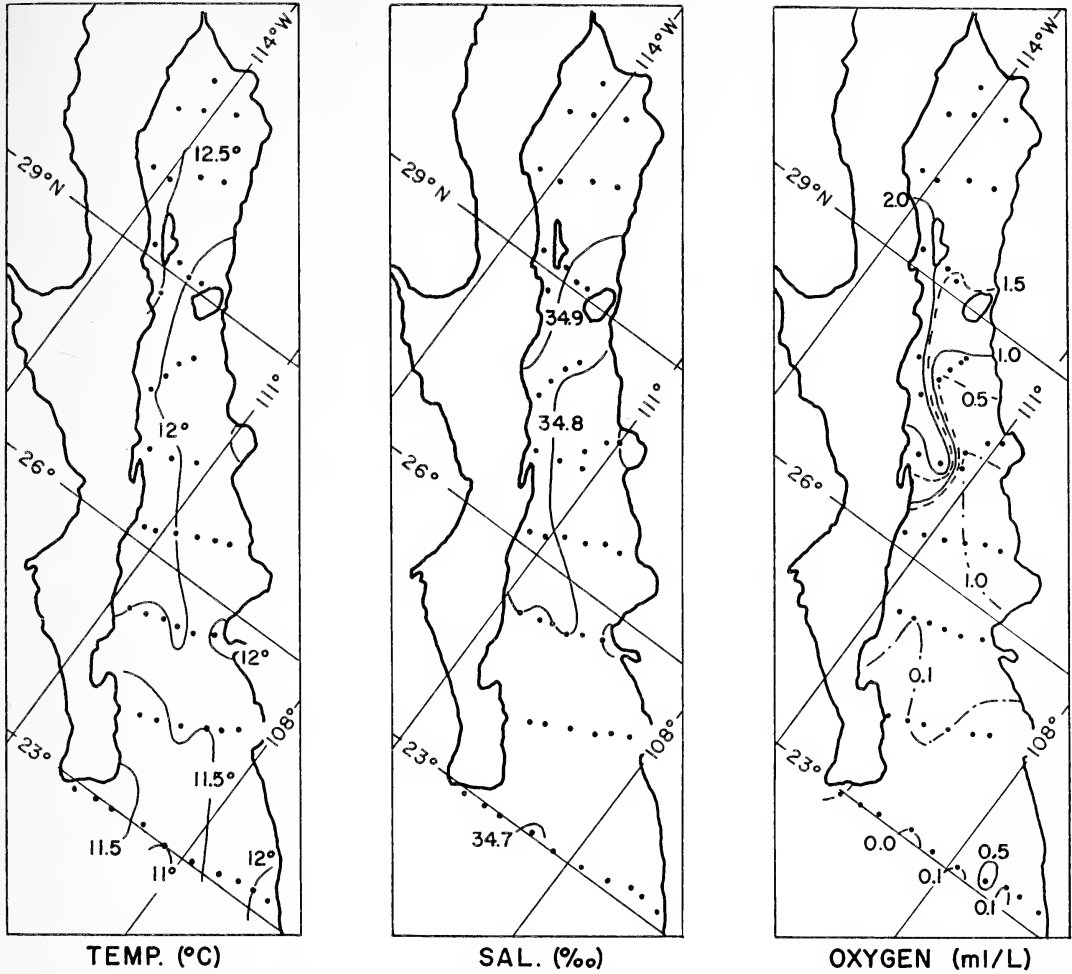In the Gulf, as elsewhere, upwelling, sink-

FIG. 18. Distribution of temperature, salinity, and oxygen at 200 m., in February and March, 1939.

ing, and convective overturn play important parts in determining the fertility of any given place. Convection is especially conspicuous north of Isla Tiburón and is responsible for the different hydrographic conditions there. Upwelling is largely found in the lee of headlands and islands, along the eastern coast with northerly winds, and along the western coast with southerly winds. Away from the shores the Gulf is fertile only in spring after considerable winter mixing has brought an adequate supply of phosphates and silicates to the surface. During the rest of the year the surface waters are relatively barren.

The field for investigations in the Gulf is nearly unlimited and it is the hope of the author that in the future increasing efforts will be directed towards the scientific exploration of one of the most fascinating seas in the Pacific, the Gulf of California.

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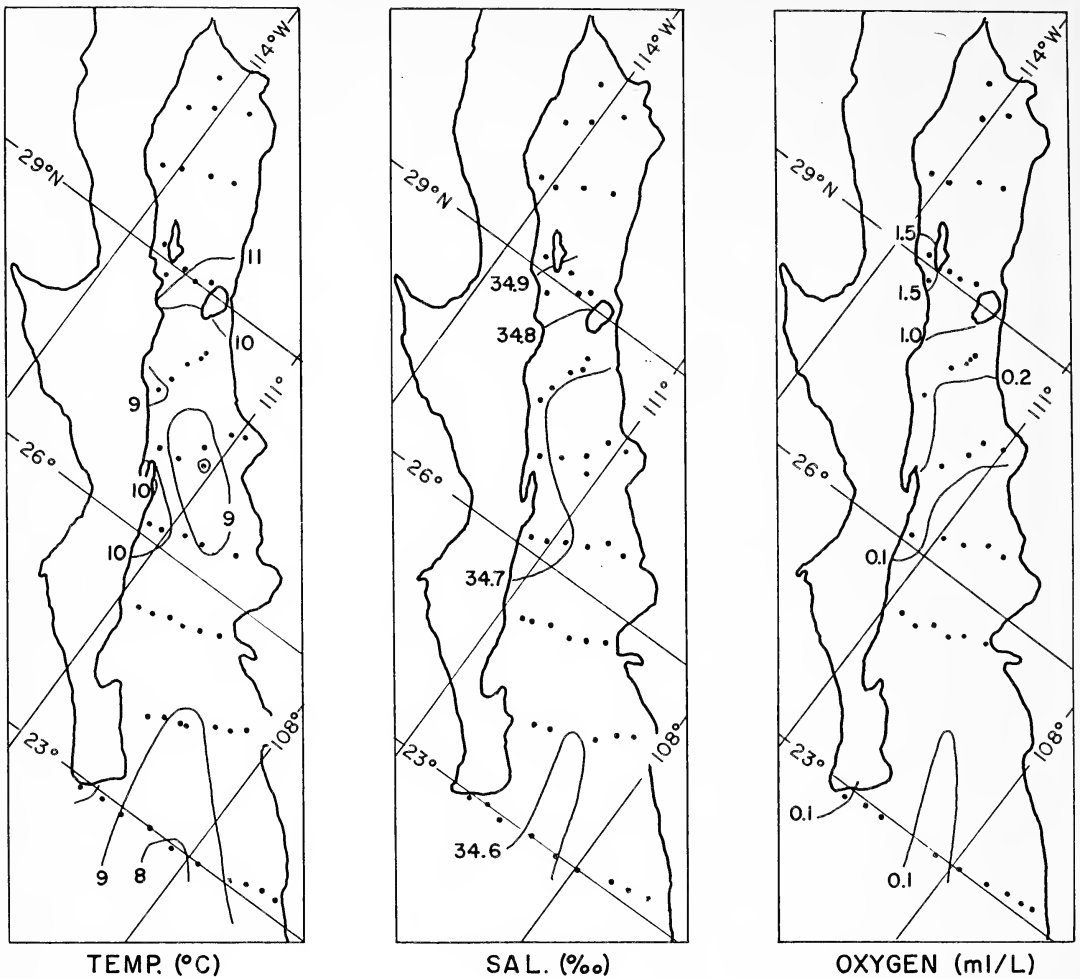
FIG. 19. Distribution of temperature, salinity, and oxygen at 400 m., in February and March, 1939.

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A Closing, High-speed Plankton Catcher for Use in Vertical and Horizontal Towing

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A FEATURE common to conventional conical nets is the speed at which they may be towed —one to two or three knots (1 kt. equals 1.85 km./hr.)—which is necessary to safe working of the gear and an undamaged condition of the catch. Increasing the speed of towing is believed to set up a zone of pressure which advances before the mouth of the net, possibly warning or otherwise causing animals to avoid capture.

Modifications in attempts to improve the efficiency of this basic type of net, include methods of opening and closing nets under water (Kemp, Hardy and Mackintosh, 1929; Marr, 1938; Barnes, 1953; Currie and Foxton, 1957); alteration of its shape, as in the Hensen and Apstein nets (Sverdrup, Johnson and Fleming, 1942), and as made by Sheard (1941), and Barnes (1953); addition of flow meters to determine the volume of water filtered (Harvey, 1934; Clarke and Bumpus, 1940; Arnold, 1952; Currie and Foxton, 1957); and means of taking series of discrete samples (Hart, 1935; Motoda, 1952).

A different approach involves the type of sampler which can be towed horizontally at higher speeds. The mouth in this type usually precedes the towing point (unlike conical nets) so that the sample is collected from undisturbed water; when combined with high speed through the water, this contributes towards collecting a wide range of organisms.

In general, high-speed catchers incorporate a type of conical net, either in a rigid frame

(Cassie, 1956), or in a rigid (metal) container (Arnold, 1952; Gehringer, 1952). Usually the area of the mouth is much restricted relative to the area available to filtering the water, but in the Gulf Sampler III (Gehringer, 1952) the diameter of the mouth (16 inches) is almost that of the contained net. Flow meters may be incorporated as in the tail of the Scripps High Speed Sampler (together with a depth recorder); in the Gulf Sampler IA (Arnold, 1952); and in mouth and tail of the Gulf Sampler III (Gehringer, 1952). To the best of our knowledge, no high-speed sampler can be closed when towing is completed.

The Continuous Plankton Recorder (Hardy, 1935) operates on the principle of a continually renewed filtering area, and, although it is a high-speed sampler, is in a different category from those already discussed.

Less attention has been paid to more rapid sampling by vertical tows. In one method (Hart, 1935) flights of small, conical nets are evenly spaced on a wire and are towed over a vertical distance equivalent to the spacing; they are then closed and hauled in. Samples are thus collected simultaneously from several levels. Motoda (1952) incorporates a series of collecting buckets in a frame; unused buckets successively lock on to the cod end of the net during a step-by-step rotation of the frame. Each bucket collects material only over a particular range of depth. None of this style of nets is towed faster than about one metre per second (two knots).

Nets for vertical towing are usually constructed somewhat differently from those for horizontal or oblique tows (Kemp, Hardy, and Mackintosh, 1929). To convert from the one use to the other may be impracticable,

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thus making various sorts of nets almost obligatory. Material thus collected could be compared only with difficulty (e.g., see Winsor and Walford, 1936; Winsor and Clarke, 1940; Barnes and Marshall, 1951). More important, perhaps, is the limitation a multiplicity of gear imposes on assessment of relative efficiencies of vertical and horizontal tows as methods of quantitatively sampling a water column.

The following account is of a plankton catcher designed for both vertical and horizontal sampling, and requiring a minimum of conversion from the rigging for one type of tow to that for the other. Its rigid outer casing is of fibreglass; it has a comparatively wide mouth, contains a conical net of stainless steel, and has been towed successfully at speeds up to 10 kt. horizontally, and 5 to 6 kt. vertically. A valve, which can be closed by a messenger, stops the flow of water into the net, and there is a depth-flow meter in the tail. The diameters of mouth and valve differ, and it is the narrower aperture of the valve that controls the flow into the catcher. It accepts 89 per cent of a column of water, of an equivalent area of cross section, at speeds between 3 and 10 kt. The result encourages us to publish details of the catcher and its performance. The principles of its construction appear sound, but some modifications are being considered in plans for a second instrument.

REQUIREMENTS FOR THE CATCHER

The requirements on which the design of the catcher was based are:
1. That collections made may be profitably subjected to quantitative analysis.
2. That speeds of 6 kt. or faster, both vertically and horizontally, may be achieved.
3. That more than one unit may be attached to a single, vertical wire.
4. That no encumbrances precede the mouth during either vertical or horizontal towing.
5. That it be versatile in catching power.

To be a "quantitative" sampler, the mouth must be closable during vertical and horizontal towing. Second, the volume of water passing through the filter must be measured. Third, development of a pressure zone preceding the mouth must be minimised by making flow through and around the catcher of low impedance.

A low resistance to flow inside the catcher, together with a long streamlined body, contributes towards fast stable towing with least drag. During vertical towing the unit is attached by its side to a weighted wire, and its ability to tow in a stable manner is relied on to reduce the angle at which it hangs (on the vertical wire). Excessive drag would act to increase the angle. The inherent stability also ensures steady true towing at the higher speeds in a horizontal direction.

In horizontal tows hauling from a point behind the mouth eliminates bridles, and other attachments, preceding the mouth. The advance of such attachments possibly warns or scares at least the more agile zooplankton. In vertical tows, the wire is to one side of the mouth. It may possibly become a relatively constant feature and therefore not be so disturbing to organisms. The mouth remains otherwise unobstructed.

Fast towing, both vertically and horizontally, and the wide unobstructed mouth are aimed at providing collections which are widely representative of the organisms encountered in a column of water.

DESIGN AND CONSTRUCTION

In Figures 1, 2, and 3 the construction and relationships of parts of the catcher are shown; Figure 4 is a photograph of the dismantled catcher, and Table 1 is a schedule of parts.

The outer shell is rigid, 7 feet long, and can be dismantled into three major sections, nose-, body-, and tail-pieces (Figs. 1 and 4, A, B, C). The nose incorporates the opening of the mouth and the closing mechanism, the body contains the conical net, and the tail the depth-flow meter and stabilizing fins. Normally the nose is bolted to the body, but the
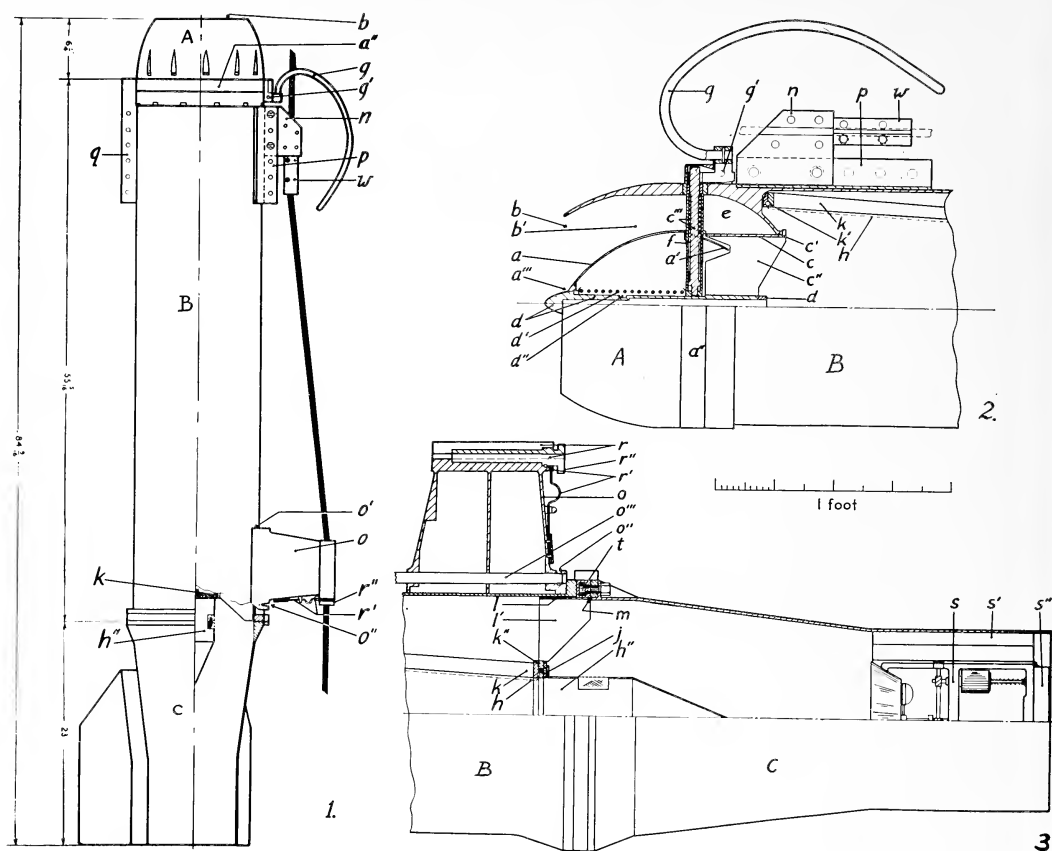
FIGS. 1–3. (1) General diagram of catcher, rigged as for vertical towing.
(2) Nosepiece, mouth chamber, and valve chamber showing the relationships of the parts to each other, to the forward end of the body and the net. Note that the valve is closed.
(3) Tailpiece showing the after end of the net, its frame, the depth-flow meter and the vertical-wire bracket.
Note: Figures 2 and 3 are to same scale and are × 2, Figure 1; for legends, see Table 1.

tail is removable and the net then can be freely withdrawn towards the rear.

Nose, body, and tail (including the fins) are manufactured from Crystic 191, an epoxy resin, with fibreglass reinforcement. These materials have important advantages. Together, they are tough, light in weight (specific gravity 1.3 approx.) and non-corrodible in seawater. Absorption of water is very low and they have proven dimensionally stable in the catcher under diverse conditions of towing and handling. They have been subjected to pressure at 1500 m. without any indication of delaminating or pulverizing in spite of small entrapped bubbles of air.

The opening of the mouth is 9 in. in diameter and leads into the mouth chamber (Figs. 1, 2, 4, *b*). Behind, and partly contained by the nosepiece, is a separate valve chamber (2, *e*). Castings forming the mouth and valve chambers are mounted on a cast bronze ring (Figs. 1, 2, 4, *a''*). The internal surfaces of the chambers and ring are continuous, and they curve inwardly towards the rear, where they form a circular opening of 7½ in. diameter. The inner surface of this acts as a bearer to the outer face of the valve (2, 4, *c'*).

The valve (Figs. 2, 4, *c*) is a short, open-ended cylinder, of 7¼ in. internal diameter.
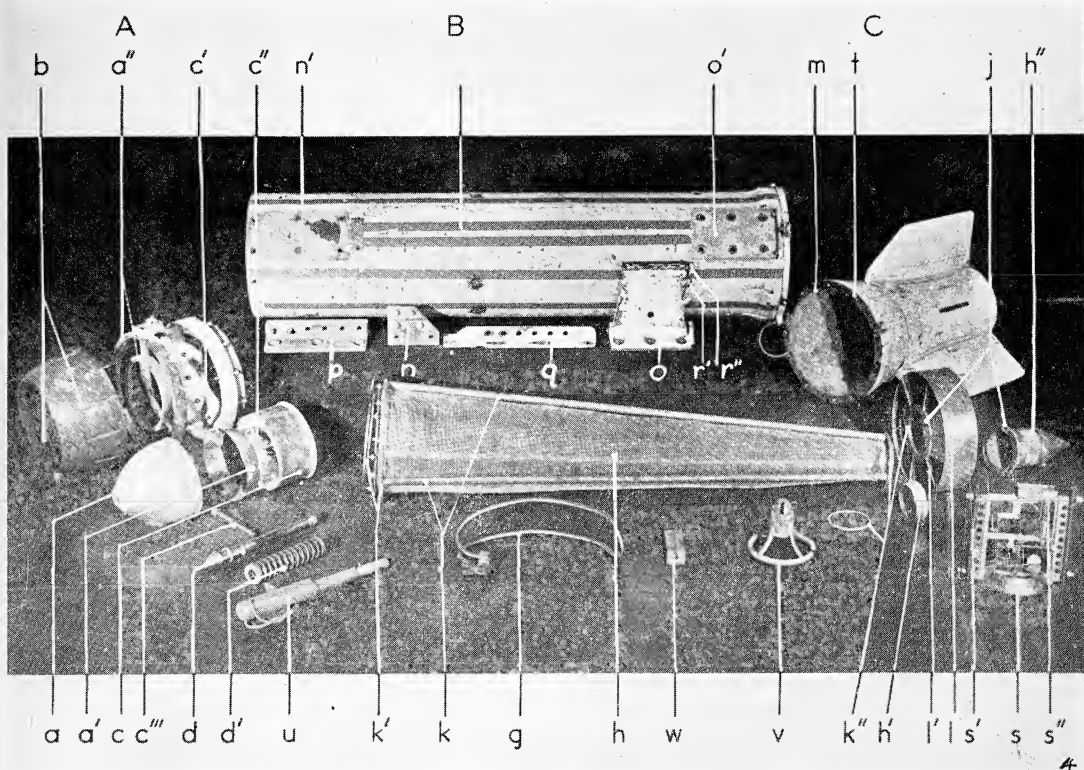
FIG. 4. The parts of the catcher displayed and showing their approximate relationships. For legend, see Table 1.

Radial fins (2, 4, c'') attach to its inner surface and to a central, stainless steel, spindle (2, 4, d) which protrudes forward from the valve and guides the valve, and around which a groove (2, d'') has been turned. When closed, the leading edge of the valve abuts against the trailing edge of a streamlined boss (2, 4, a), set in the mouth, and the forward end of the spindle closes a hole of 1 5/16 in. diameter (2, a''') in the front of the boss. A faring (2, 4, a') extends rearward from the boss to improve streamlining. Four holes, 3/16 in. diameter, pierce the front end of the boss. When the unit is raised from the water, air enters by these and enables entrapped water to escape freely.

The valve is opened by pushing the spindle towards the rear with a thruster or loader (4, u) through the hole in the boss. This compresses a coiled spring (2, 4, d'), fitting round the spindle. The valve is locked open by a spring-loaded, radially mounted, detent pin (2, 4, c''') which clicks home in the groove turned in the spindle. The pin is withdrawn from the detent position when the release arm (1, 2, 4, g) is actuated by the weight of a messenger (4, v; 6, 7). The spring-loaded spindle is thus released and moves the attached valve rapidly forward, shutting off the flow of water to the net.

The filtering net (Figs. 2, 3, 4, h) is of stainless steel mesh; joints are folded, spot welded and then sealed with "Araldite." The ratio of the total area of the filtering holes and the valve (see below) of the catcher is approximately 11 for a net of 40 meshes to the inch and 14 for a net of 10 meshes to the inch. A frame encloses the net. It consists of three tubular brass struts (1, 2, 3, 4, k) attached to a forward clamp ring (2, 4, k'),

TABLE 1

LIST OF PARTS OF CATCHER, DESIGNATED IN FIGURES 1 TO 4

SECTION	DESIGNATION	PART	FIGURES IN WHICH PART IS PRESENT			
			1	2	3	4
Nosepiece.......	A		x	x		x
	a	Boss................................		x		x
	a'	Boss, after faring of.....................		x		x
	a''	Boss, supporting ring (Bronze)..............	x	x		x
	a'''	Boss, forward hole in.....................		x		
	b	Mouth................................	x	x		x
	b'	Mouth, chamber..........................		x		
	c	Valve.................................		x		x
	c'	Valve, bearing surface for..................		x		x
	c''	Valve, radial supporting fins................		x		x
	c'''	Valve, detent pin and spring................		x		x
	e	Valve, chamber..........................		x		
	d	Spindle to valve.........................		x		x
	d'	Spindle, coiled closing spring................		x		x
	d''	Spindle, groove for detent pin...............		x		
	f	Housing for detent pin and spring............		x		
Bodypiece.......	B		x	x	x	x
	g	Closing mechanism release arm...............	x	x		x
	g'	Closing mechanism release arm, attachment point...........................	x	x		
	h	Net, (Stainless steel)......................		x	x	x
	h'	Net, stretcher ring for cod end..............				x
	h''	Net, plankton bucket......................	x		x	x
	j	Locking studs for bucket...................			x	x
	k	Net frame, (struts of).....................	x	x	x	x
	k'	Net frame, forward clamp rings..............		x		x
	k''	Net frame, after clamp rings................			x	x
	l	Net frame, thrust ring.....................			x	x
	l'	Net frame, radial fins between thrust ring and struts................................			x	x
	m	Thrust surface of tail......................			x	x
	—	Towing brackets..........................	x	x	x	x
	n	Towing, vertical, forward..................	x	x		x
	n'	Towing, vertical, attachment area				x
	o	After, vertical bracket.....................	x		x	x
	o'	After, vertical, attachment area.............				x
	o''	After remote messenger release point........	x		x	
	o'''	After remote messenger release rod..........			x	
	p	Horizontal towing bracket..................	x	x		x
	q	Depressor bracket.........................	x			x
	—	After bracket, wire-catch...................	x		x	x
	r	Wire-catch, slot for wire...................			x	
	r'	Wire-catch, locking catch and spring..........	x		x	x
	r''	Wire-catch, rotating central spindle...........	x		x	x
Tailpiece........	C		x		x	x
	s	Depth-flow meter.........................			x	x
	s'	Depth-flow meter, runner mounting...........			x	x
	s''	Depth-flow meter, revolution counter..........			x	x
	t	Locking studs of tail......................			x	x
Miscellaneous...	u	Loader.................................				x
	v	Messenger..............................				x
	w	Wire stop...............................	x	x		x

which holds the upstream end of the net to the frame. At the rear the struts attach to a flange (3, 4, k'') which fits snugly about the cod end of the net. The cod end, in turn, is forced against the flange by a conically shaped stretcher ring (4, b'), fitted internally. Radial fins (3, 4, l') extend outward from the flange to a deep thrust ring (3, 4, l). When the frame and net are inserted into the body from the rear, the thrust ring locates the after end (Fig. 3), and the clamp ring locates the forward end (Fig. 2). The forward end of the tail has an internal diameter 3/16 in. less than the after end of the body. When the tail is on, an internal lip is formed (3, 4, m) which abuts against the rear edge of the thrust ring, and provides a thrust surface. The assembly serves to push the net from the downflow end into the water entering through the valve. On removing the tail the frame is retained by a spring clip which is attached to the thrust ring, and which engages with the body. The tail is locked onto the body by a simple, external catch after a part turn has been made over locking studs (3, 4, t). The plankton bucket (1, 3, 4, b'') is removed after releasing a clip and also making a part turn over locking studs (3, 4, j). Its rear end is streamlined where it extends back into the tail piece.

The depth-flow meter (Currie and Foxton, 1957) is fastened in the tail on two runners (Figs. 3, 4, s, s'). It can be slid rearwards, clear of the end of the tail, to facilitate its being handled and read. The impellors turn only with forward motion of the catcher and rotate a drum on which a smoked glass cylinder is slipped. We have modified the meter so that the drum in turn drives a dial-type revolution counter (3, 4, s''). A Bourdon pressure unit is attached to a pen and, on reduction of pressure, causes a longitudinal trace to be made on the smoked cylinder. During a vertical tow, this is combined with rotation of the cylinder, when a helical trace results, from which depth and flow can be obtained. In a horizontal tow, the revolution counter gives the number of turns made by

the cylinder while the trace on its surface gives the depth to which the catcher was lowered, and at which it was towed. The amount of water which passes through the net during the period of lowering is also indicated.

The weight of the catcher is 120 pounds (54.5 kilos) when rigged for horizontal towing, and 130 pounds (59 kilos) for vertical towing. To these must be added, respectively, 45 pounds (20 kilos) for a depressor (Fig. 7), and 45 pounds for a lead sinker (Fig. 5).

TOWING ATTACHMENTS AND RELEASE ARM

Vertical Towing

Vertical towing requires forward and after brackets for attaching the wire to the catcher (Figs. 1, 2, 4, n, n', and o, o'). The catcher is supported by the forward bracket on a stop (1, 2, 4, w) on the wire; the after bracket is a spacer. Free rotation about the wire is allowed. The wire is inserted via a slot (3, r) into a central rotating portion (1, 3, 4, r''), which turns through 180° and is locked in place by a spring clip (1, 3, 4, r'). Initially forward and after brackets were similar. Each held the wire about 7 in. off the side of the catcher, but this method introduced many difficulties and had to be abandoned. In the method now employed the after bracket remains, but the forward bracket (a temporary one, see Figs. 1, 2, 4, n) offsets the wire by only 3 in. It is inserted in, and attached to, the horizontal towing bracket (1, 2, 4, p) which has a U-shaped section. Underwater observations indicate that at a vertical towing speed of 2 to 3 kt. the catcher is at an angle of about 5°, but as the speed is increased to 6 kt. the angle progressively decreases until for all practical purposes, the unit tows in a vertical position.

The heavy sinker (45 pounds, Fig. 5) is not necessary when towing vertically, but is essential during rapid lowering to reduce a tendency in the catcher to dive nose first. As the valve is open, the catcher would be fishing
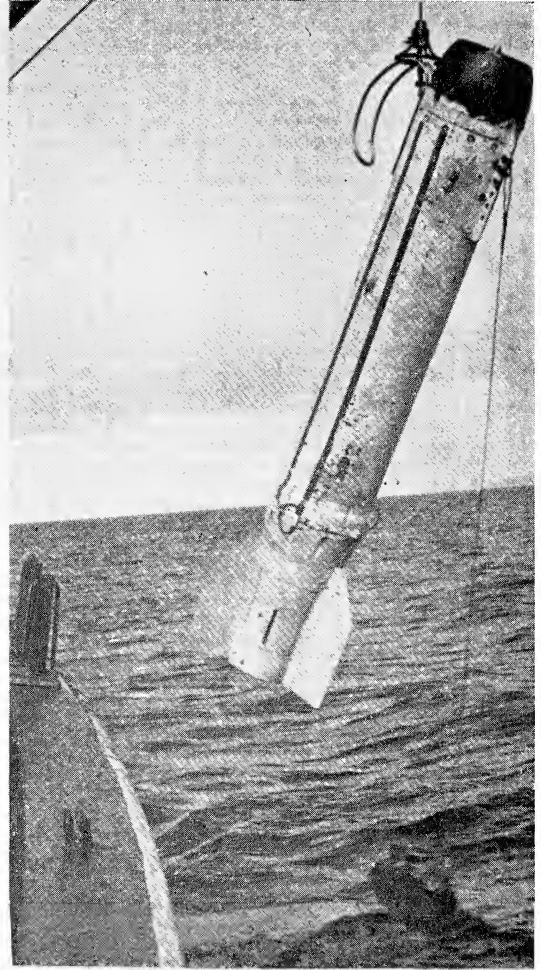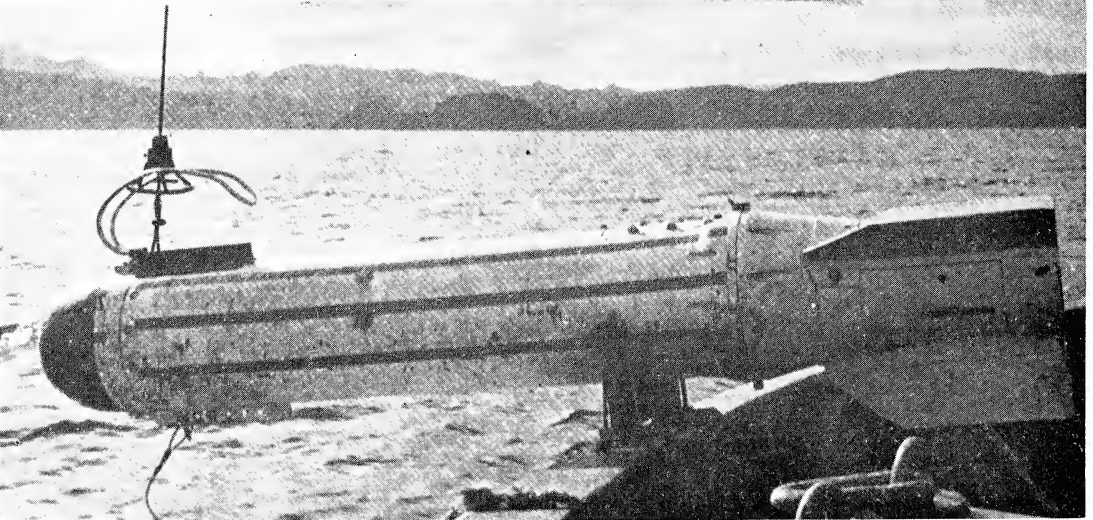
and the flow-meter registering were this permitted.

To facilitate using flights of catchers on a vertical wire, a mechanism for releasing a messenger from the after end of each catcher was constructed. The impact of the messenger on the release arm set free the lower messenger which, in turn, triggered the closing mechanism of the next catcher down the wire, and so on. Part of the mechanism was in the rear bracket and is shown in Figure 3, *o''*, *o'''*; some of it was also built into the original forward bracket, but this has not been continued in the present one. The assembly has now been dismantled, but there are few difficulties to its reintroduction.

Horizontal Towing

To convert from the rigging for vertical, to that for horizontal tows, takes about five minutes. The wire stop, and the after and forward brackets are removed. The eye of the towrope is inserted into the bracket (Figs. 1, 2, 4, *p*) used for horizontal tows, at a point close behind the attachment of the release arm of the closing mechanism (1, 2, *g'*).

Because the catcher is required to be towed at depth, a 45-pound depressor (as supplied by Scripps Institution of Oceanography) is attached (Fig. 7). It hangs on a free wire from a bracket on the underside of the forward end (1, 4, *q*). It is most efficient, but in rough weather it is difficult to handle, and causes further trouble when it snatches into passing waves. A removable, adjustable, built-in depressor would be desirable in a future model.

The Release Arm (Closing Mechanism)

The same release arm (Figs. 1, 2, 4, *g*; 5, 6, 7), of stainless steel tubing, operates the clos-

ing mechanism in vertical and horizontal towing. It is essential that the surface which the messenger strikes is approximately at right angles to the run of the wire. Provision for this is made in the curvature of the arm. The messenger (4, *v*; 6, 7) carries a ring on a frame from its base, so that the two sides of the arm are struck, wherever the wire is located between them.

Features which are novel to the plankton catcher are its fibreglass construction, the sleeve-type valve for stopping the flow of water into the net, and the readiness with which conversion from a catcher for vertical towing to one for horizontal towing is carried out (without alteration of the catching power).

EFFICIENCY TRIALS

Trials to determine the efficiency with which the catcher accepts the water presented to it, and the effects that nets may have, have been carried out. The course and nature of the flow through the mouth and valve are indicated by tests with a two-dimensional model.

Model Tests

The model of the mouth and valve is a full-scale longitudinal, sagittal section, one-half inch thick, which is sandwiched between sheets of "Perspex," screwed to the model and to separating pieces at the sides. A diffuser placed between inlet ports and model ensures that parallel lines of flow are presented to the model. Flow lines were indicated by cotton threads attached to a small metal sledge (made in the form of a box, but open to the flow at the sides) which was manoeuvred about the model with a magnet. The width of the test channel is 18 inches by one-half

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FIGS. 5–7. (5) The catcher before lowering for a vertical haul. The lead sinker just clears the surface of the water. (The dark stripes on the body are "Scotchlite" fluorescent tapes which assist during subsurface observations.)

(6) The catcher, rigged for horizontal towing, hanging in the guardrail crotch. The nose-down position, as illustrated, is a steady one when moving between stations. Until the net is withdrawn, however, the nose is kept higher than the tail.

(7) The catcher as recovered from a horizontal tow. It is closed, as shown by the head of the spindle protruding from the mouth; a messenger rests on the release arm of the closing mechanism. The depressor hangs below the catcher.

inch, of which the mouth intercepts 9 in. The remaining 9 in. is divided between the channels lateral to the model. Each of these narrows from 4½ in. to 2½ in.

Figure 8 is a composite drawing and shows the flow lines at an estimated 4 kt. (left half) and 1 to 2 kt. (right half). A positive pressure gradient builds up lateral to the model, as a result of the restriction to flow due to the narrowing of the channels, and is probably responsible for the inwardly sloping flow lines at, and preceding, the leading edge of the mouth. There is a similar, but stronger, inflow towards the hole in the front of the boss. A positive pressure gradient again would seem to be the cause, but arising in the nature of the flow around the boss, and along the channels of mouth and valve chambers. The effects of the gradients become more evident at the faster rate of flow. It is possible that the representation of the flow lines preceding the leading edges of the mouth of the model are not what would obtain in open water with the catcher. However, flow lines into the hole in the boss are distorted by pressure developing as a result of the design of the mouth and valve chambers, and in this case the effect would probably also occur with the catcher. Should either gradient persist during towing, a zone of higher pressure would precede the mouth. This feature is undesirable, although the end result may well be to reduce the actual mouth area to an effective one more nearly equivalent to the area of the orifice controlling the flow into the catcher, namely the valve (see later).

Flow through the mouth and valve chambers (Fig. 8) follows the channels "lateral" to the boss in clean and definite lines. Compression of the lines towards the outer surface of the channel, obvious at the faster rate, suggests that more water flows along this margin. At the higher rate, the lines leave the margin at a position preceding the valve and tend to straighten. The faring at the after end of the boss deflects the flow towards the valve where this occurs. Inside the boss, the main
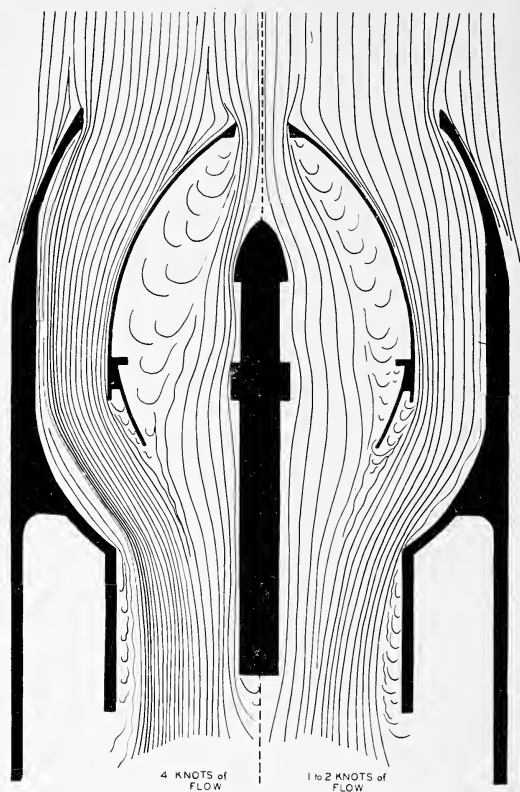

FIG. 8. Composite drawing showing flow lines for estimated speeds of 4 kt. (left half) and 1–2 kt. (right half).

flow forms a distinct pattern near the spindle, but strong turbulence is evident beyond this. The main flow assists effectively in forcing the water from mouth and valve chambers into the valve opening. Even so, and largely because there is a sharp change of direction in flow from valve chamber into the valve, cavitation and turbulence are induced on the inner face of the valve. Therefore the valve may not be accepting water to its full capacity.

These tests demonstrate that the flow patterns in mouth and valve chambers are satisfactory, evidence which is of value in assessing whether this design is functioning adequately. It is regretted that higher rates of flow were not available for further tests.

Efficiency of the Catcher

Relative efficiencies between the catcher

rigged with no net, with a net of 10 meshes/in., and with a net of 40 meshes/in., are shown in Figures 9 and 10. The catcher with each rig was towed over a straight course of one nautical mile (determined by radar). Each run was timed, and calculated speeds ranged between 3 and 9 knots. The flow meter was read at the beginning and end of each run.

Meter readings were highest when no net was enclosed—about 390 revolutions/mile (Fig. 9). The 10-mesh net caused a reduction to 345 revs./mile (about 11.5 per cent), and the 40-mesh net to 310 revs./mile (about 20.4 per cent). Thus, some restriction to flow is introduced with the nets. That this is due to frictional resistance offered to flow past the strands of the net, and not to insufficient filtering area, is suggested by two sources of evidence. When moderate blooms of diatoms are encountered the 40-mesh net clogs at first only in the lower 12 to 24 in., indicating that filtering is occurring over a relatively small area of the net. More convincing evidence is illustrated by Figure 9, where revolutions per mile of tow are plotted against speed of towing. It is apparent that over the range of speeds utilized there is no reduction in the number of revolutions, for each of the rigs investigated. This is an important point and shows that the quantity of water filtered per unit of distance is constant for each rig, although the volume presented per unit of time increases with the speed. If there were an insufficient area to filter the flow (or if there were other restrictions, the effects of which increased with speed), less water per unit of time would be accepted at the higher speeds and fewer revolutions recorded for a given distance.

An approximate calibration of the meter has been made for several speeds. It was towed mounted in a straight tube, 3 ft. long and 9 in. in diameter (the same diameter as the mouth and tail of the catcher). It is assumed the tube accepts all of the volume of water in a column with a cross-sectional area equal to the tube. The meter recorded
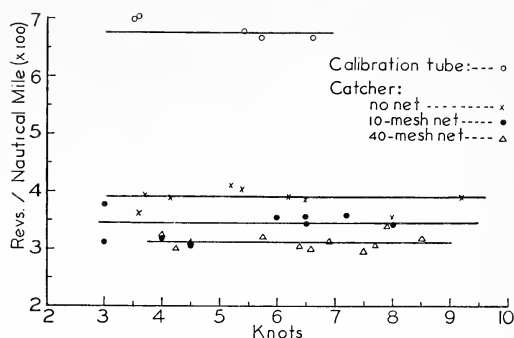

FIG. 9. Revolutions of the depth-flow meter per nautical mile plotted against speed of towing. The uppermost curve is from the readings obtained when towing a straight tube, 9 in. in diameter; the lower three curves result from towing the catcher with no net (upper), with a net of 10 meshes (middle), and a net of 40 meshes/inch (lower).

approximately 675 revolutions per nautical mile. Against this was the recording of 390 revs./nautical mile for the catcher (without a net). This represents an apparent acceptance value for the catcher of only 57.8 per cent (Fig. 10). Such a value suggests a major restriction to flow in the catcher, and it is probable that this is caused by the narrower orifice, namely the valve. This being so, the ideal acceptance would be in the ratio of $\dfrac{\text{area of valve}}{\text{area of mouth}}$, which is 0.649, i.e., the valve should accept 64.9 per cent of the water presented to the mouth. That the actual acceptance (57.8 per cent), by the valve is lower than its theoretical acceptance (64.9 per cent), indicates other, but less obvious, restrictions to flow. Cavitation on the inner face of the valve, and some details of the construction, are probably factors to be considered.

The volume of water in a column one nautical mile long (1.85 km.), of a diameter of 9 in. (22.9 cm.), is 76.7 m³. The meter in the calibration tube recorded 675 revolutions for this volume, which is equivalent to 0.114 m³/rev. The tail of the catcher is also a tube of 9 in. diameter, and it may be assumed the flow patterns in it are similar to those in the calibration tube. Therefore, a meter reading of 390 revs./mi. (no net in the catcher) rep-

resents an accepted volume of 390 times 0.114, i.e., 44.3 m³. Ideally, the valve should accept 64.9 per cent of the volume presented to the mouth, i.e., of 76.7 m³, which is 49.8 m³. On this basis the valve accepts water with an efficiency of 89 per cent. Since frictional resistance is introduced by the nets the flow is reduced still further. For the net of 10 meshes per inch, the reduction is 11.5 per cent so that 39.2 m³ is accepted (78.8 per cent efficient); for the 40-mesh net the volume is reduced by 20.4 per cent which is 35.2 m³ (71 per cent efficient). (See Fig. 10, upper curve.)

These data demonstrate first, that the narrower aperture of the valve controls the flow of water into the catcher. Second, the nets introduce restrictions to flow, but as their filtering areas are adequate in relation to the area of the orifice controlling the flow, the restrictions do not change with speed, at least between 3 and 10 kt. Third, the catcher deals reasonably efficiently (89 per cent) with a
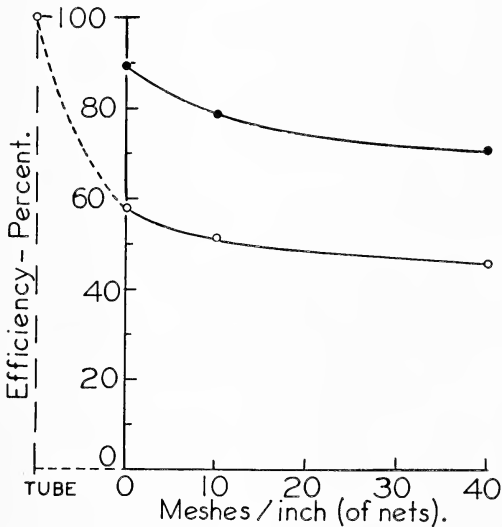

FIG. 10. Lower curve: percentage efficiencies of catcher with no net, and nets of 10 and 40 meshes/inch, relative to the calibration tube (of 9 in. diam.) when this is assumed to accept 100 per cent of the column of water presented to it. Upper curve: percentage efficiency of the catcher with no net (an absolute efficiency 89 per cent for a valve aperture of 7¼ in.), and with nets of 10 and 40 meshes per inch.

volume of water equivalent to unit length times the area of the valve.

Flow Through the Catcher

Flow through the body and tail of the catcher is controlled predominantly by the areas of their cross sections relative to that of the valve. The ratio between the areas of valve and body is 2.75, and between valve and tail, 1.55. If the rate of flow through the valve is assumed to equal the towing speed, then at 10 kt. the flow in the body is 3.65 kt. and in the tail, 6.5 kt. These rates assume an efficiency of 100 per cent by the valve; reduction of flow by the nets, and an efficiency value which is below 100 per cent, will lower them. The moderate rate in the body probably accounts for the undamaged condition of the plankton (see later).

There is probably an optimum rate of flow through the body (and the filter) for most efficient working of the unit. This becomes a factor in any new design which proposes a change in the diameter of the controlling orifice. Thus, an increase in the diameter of the valve to 9 in. (which, it may be assumed, will equalize the volume accepted by the valve and that presented to the mouth) will reduce the ratio between the cross-sectional areas of body and valve to 1.78. Rate of flow through the body would then be 5.6 kt. for a towing speed of 10 kt. Such a rate may damage organisms beyond an acceptable amount, or the frictional resistance of the nets may increase to a degree where it begins to seriously reduce the efficiency of the catcher. It is believed that the diameter of the valve can be increased, but this will probably require the diameter of the body to be increased also, so that flow does not exceed an acceptable speed, say of 4.5 kt. at a towing speed of 10 kt.

Plankton Catching

Trials of the ability of the catcher to collect plankton have proceeded to the extent that circumstances have permitted. It has not been possible to make repetitive hauls in one place

or numerous series of hauls, in order to assess the versatility and reliability of the catching power of the unit. A conventional type of net, of 50 cm. diameter (Bary, 1956), was twice fished alternately in horizontal tows with the catcher, and other horizontal tows have been made with the latter. Some vertical tows with the catcher have been compared with collections from a Nansen-type closing net. Whenever a net has been included during trials with the unit, the bucket has been examined for plankton.

The range of organisms and the quantities collected are most encouraging. Several of the smaller species of pelagic fish, fish larvae, squid, and larger euphausiids and shrimp have been captured. Also, common forms such as copepods, chaetognaths, salps, and larval decapods are collected, sometimes in high numbers. When the catches of the 50-cm. net and the catcher were roughly equilibrated for differences in size of mesh, area of mouth, and distances towed, the catcher was believed to have collected a greater quantity of larger organisms, including fish and shrimp, than the net. Collections made during the vertical hauls with the 70-cm. Nansen-type of net and the catcher were similar in the range of organisms captured. Specimens are alive (except fish larvae) and quite undamaged at towing speeds up to 8 kt.

Although test hauls with the catcher are few, those made to date suggest it collects a representative range of organisms—a range which may be comparable with that taken by the 70-cm. Nansen closing net.

OPERATION

A "high-speed" plankton sampler, as well as being towed at fast rates, must also be quickly and easily handled on deck, recovered from, launched, and lowered to the level at which it is to be towed, and emptied of its catch.

On raising the present catcher from a horizontal tow, the depressor is lifted onto a hook attached to the ship's side (not necessary in calm water), and the rear end of the catcher is rested in the crotch on the guard rail (Fig. 6); the meter is read (or the smoked cylinder renewed), and tail and net are removed. A second net and frame can then be slipped into the body and the tail replaced. The unit is lifted over the side and while hanging free of the rail, the valve is opened. The depressor is then freed, and the whole is lowered into the water. For a team of three (one working the winch), the time taken on this routine is about two minutes. The ship may continue to steam at from 6 to 8 kt. The used net is washed down with sea water from a hose and the catch preserved; the net is then ready for the next tow.

To reach the required depth of a horizontal tow, the catcher is allowed to dive on an almost free-running winch, and a length of wire is veered equivalent to 2.5 times the depth (a ratio of approximately 1:2.5 was found to apply up to 100 m., but may not do so at greater depths. The depth-flow meter provides a check on the depth reached.) Meanwhile the ship may continue underway, altering speed to the towing speed, if necessary. At the end of the tow, the catcher is closed by messenger, recovered, and the usual routine followed.

In vertical tows with a single unit (no tows with multiple units have been made), the routine is similar. Additionally, the wire is released from the after bracket before the tail is lifted onto the rail, and is replaced again before lowering. The terminal sinker need not be lifted, but may require steadying with a strop or boat hook in rough weather.

Lowering for the vertical tow is rapid when compared with a Nansen-type of net. It is necessary to brake the winch to a vertical speed of about 4 kt. so that a strain is maintained on the wire, otherwise the catcher may dive nose first (see earlier). The haul is as rapid as the winch permits, or as is desirable. At depths below 750 m., delays of a minute or two are necessary, before commencing to

haul, because of the falling time of the messenger. However, they do not greatly affect the very considerable saving of time accruing from the relatively rapid lowering, hauling, and recovery of the catcher from, and its return to, the water, during a series of vertical tows.

Before quantitative investigations can approach absolute values, as opposed to relative values, the efficiency and characteristics of the catching gear should be known. Currie and Foxton (1957) have provided pertinent data for their new quantitative (Nansen-type) net, but the equivalents do not seem to be available for high-speed samplers. The meter for such a sampler requires calibrating for flow, but in a situation remote from influences of the gear which may interfere with its functioning (e.g., in a calibration tube), and over the speeds at which the sampler is likely to be used. Values obtained must be considered in relation to the flow through the sampler itself, with and without nets included, and again over the relevant range of speeds. The proportion of the column of water (of unit length and of a cross-section equal to that of the controlling orifice) accepted by the gear under conditions of differing rigs and speeds now can be estimated fairly accurately. That is, the efficiency of the catcher can be determined. The optimum towing speed can now be established, together with the effects on flow of nets of differing meshes, or of clogging. With these data, one may reasonably study whether the catcher is collecting a representative sample of the organisms it encounters, and thus make an appreciation of the true density of the plankton population being investigated.

SUMMARY

A plankton catcher is described which has been towed successfully at speeds up to 10 kt. horizontally, and 5 to 6 kt. vertically. It can be closed during either tow. To convert from the rigging for one type of tow, to that for the other, is rapid and easy and is believed not to alter the catching ability of the unit.

A depth-flow meter is included in the catcher. It has been calibrated by towing first when mounted in a tube of equal diameter to the mouth of the catcher (9 in.), and second, in the catcher, at speeds between 3 and 9 kt. The catcher was towed without a net included, and successively with nets of 10 and 40 meshes to the inch. Data from these tests show that the valve of the closing mechanism ($7\frac{1}{4}$ in. diameter) controls the flow into the catcher; about 89 per cent of the water presented to the valve is accepted. A net of 10 meshes per inch further reduces flow by 11.5 per cent, and one of 40 meshes by 20.4 per cent. Frictional resistance to flow, offered by the meshes, is believed to be responsible as the filtering area of either net is more than adequate to filter the quantity of water presented, at speeds to 10 knots.

Plankton is mostly alive and undamaged. Indications are that a representative range of organisms is being captured, including small squid and pelagic fish and the larger pelagic crustacea.

and Ratings of H.M.N.Z.S. "Lachlan," for facilities for additional trials at a critical stage of development; and the Officers and Crew of the Royal N. Z. Fleet Auxiliary "Tui," especially for their willing cooperation and considerable assistance with the later more exacting trials. We are much indebted to Mr. E. J. Thornley, Senior Photographer, D.S.I.R., and Mr. R. Redfern, Photographer, Dominion Physical Laboratory, for assistance with ciné and still photographic records; to Mr. Ken Gibbon, Dominion Physical Laboratory, for making the very useful underwater observations; and to numerous colleagues for help and many ideas.

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Is the Spear of Istiophorid Fishes Used in Feeding?[1]

Robert L. Wisner[2]

THE SPORT OF ANGLING for spearfishes—the several marlins and sailfishes of the family Istiophoridae—has fostered many books and articles on the behavior of these large fishes. The swordfish, *Xiphius gladius* Linnaeus, comprising the family Xiphiidae, also commands a very considerable following among saltwater anglers and is the subject of an extensive literature. Certain beliefs have arisen concerning the behavior and habits of the fishes comprising these game fish families, particularly as to their methods of obtaining food. It seems worthwhile to attempt now an evaluation of the accumulated evidence. Only the true spearfishes, particularly the marlins, will be considered in detail. The broadbill swordfish will be mentioned only occasionally, and the conclusions reached do not necessarily pertain to this fish.

Angling lore is replete with reports of such fishes stunning prey and trolled fish baits with a blow of the spear before devouring them. The time-honored belief that the spearfishes possess their spears for the express purpose of striking or stabbing prey, however, may now be questioned. Recently accumulated evidence indicates that such fish can exist quite readily without a spear to aid in obtaining food. Other evidence has cast some doubt as to whether the spear is at all commonly employed in such a manner.

RECORDED OBSERVATIONS OF FISH WITHOUT SPEARS

Moore (1950) reported on a spearless black marlin, *Makaira mazara* (Jordan and Snyder), that was landed at a commercial fish market in Honolulu, Hawaii, without indicating the length of stub remaining. The nature of the wound indicated some time lapse since the loss. The specimen weighed 545 lbs. and was judged equal in physical condition to normal fish of the same species.

Mr. Vernon E. Brock, Director, Division of Fish and Game, Hawaii, in correspondence reports ". . . a spear removed from a marlin which has been broken with the remaining part that is spiraled like a corkscrew. The fish from which the spear was taken was, according to the fishermen, normal in all respects."

Morrow (1951) reported that a 172-lb. striped marlin, *Makaira mitsukurii* (Jordan and Snyder), taken with sporting tackle and trolled bait at Otehei Bay, New Zealand, had the spear broken off on a long slant reaching from several inches behind the mandible tip to within a few inches of the eye. The break had completely healed and was well covered with skin. The injury had affected the fish further in that the mouth was prevented from closing completely, one side remaining partly open. However, the fish appeared to have had no difficulty in taking the bait and gave a battle said to have been entirely normal for a fish of its weight.

Farrington (1942: 110) reported numbers of marlin with spears broken off. This observation was made at Guaymas, Sonora, Mex-

ico. Grey (1926: 105) mentioned a marlin in New Zealand waters that had a broken spear. The region of the break is not indicated, nor is the amount missing. Grey states, "Deprived of his weapon of defense and for procuring food, this marlin might well have been expected to be thin, flat, in poor condition. Nevertheless, he was solid, fat, in splendid shape. He had been compelled to rely on his speed."

In September, 1952, the author examined two spearless striped marlin at the Marlin Club dock at San Diego, California. Each was captured with sporting tackle and trolled bait. Each spear had been broken off at about the tip of the lower jaw, as in Figure 1. Since both stubs had healed completely and were well covered with skin, a considerable time must have elapsed since the injuries. The fish weighed, respectively, 149½ and 186 lbs. (official club weight). These fish were of at least average weight for their length (Fig. 3). Morphometric data obtained on both specimens when compared with those of normal fish of the same body length and weight disclosed no significant differences in body proportions.

The stomach contents of the smaller fish comprised the remains of 8 Pacific sauries, *Cololabis saira* (Brevoort), totalling 349 cc. The larger fish contained 5 small yellowfin croakers, *Umbrina roncador* Jordan and Gilbert, totalling 785 cc., a small halfmoon, *Medialuna californiensis* (Steindachner), 105 cc., and 1 trunk section of a Pacific saury, 23 cc. The first fish had eaten a main item in the diet of local marlin, as determined by Hubbs and Wisner (1953), but its stomach contents were of less than average volume. The second had eaten more than an average amount, but chiefly of a shore species not otherwise encountered in the food studies.

A third spearless striped marlin was landed at the San Diego Club on September 17, 1955. This fish was not examined by the author, but was reported to have been normal in all re-
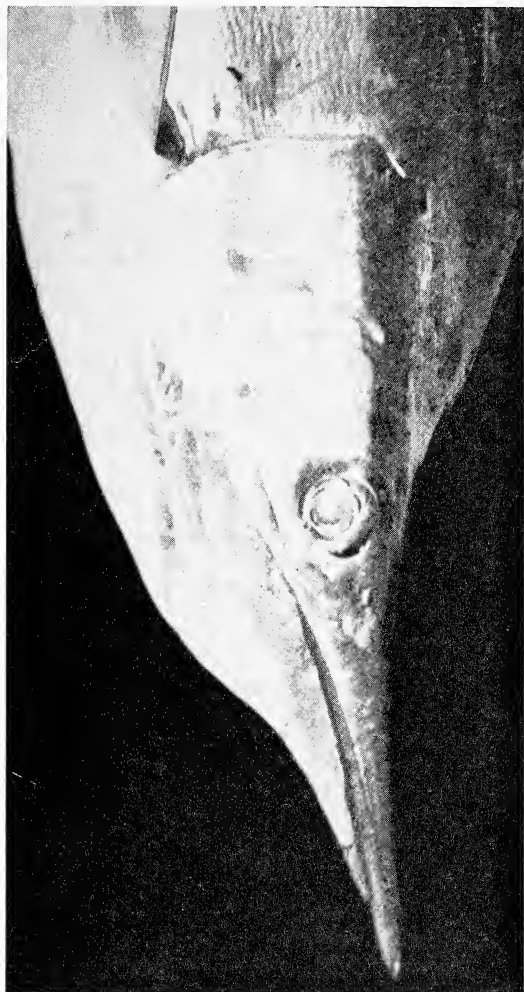

FIG. 1. Spearless striped marlin, weighing 149½ pounds. Photographed at the San Diego Marlin Club, Sept. 13, 1952, by R. Van Nostrand.

spects and fought strongly. The stub was reported to be smoothly healed and covered with skin. A fourth spearless fish, landed in September, 1956, also was reported to be quite normal despite its loss of spear. This fish also was not examined by the author.

Gudger (1940) cited many examples of portions of spears having been broken off at a considerable period of time before capture. All these fish had apparently survived the wound and had flourished since. Unfortunately, most reports did not estimate the amount of spear missing. One account ap-

proaches the incredible. During the Michael
Lerner Australian-New Zealand Expedition,
Miles Conrad reported seeing a marlin with
the spear sawed off, and yet the fish had
survived. The spear had been removed by a
square cut about midway between the tip of
the lower jaw and the anterior edge of the
eyes—the point generally selected for sawing
off a spear trophy. The fish had evidently
been caught by an angler, and, when the spear
had been removed, had escaped to the ocean.
The growth of skin that had formed over the
stub still retained the rosy glow of healthy
healing. The fish was reported to be thinner
than a normal fish of its size. Without doubt
a fish so injured as to leave the upper half of
its mouth permanently open with but half an
upper jaw would be seriously handicapped in
feeding. The previously cited injuries had at
least left the fish with mouths somewhat
suited for grasping and holding prey.

As stated by Morrow (*op. cit.*), "It is obvious
the spear is not absolutely essential to the
well being of the spearfishes." The four speci-
mens under the immediate cognizance of the
author, as well as those reported by Moore,
Morrow, Brock, and Gudger, had apparently
existed in normal fashion despite the loss of
the spear. None of those taken on sporting
tackle had given any marked indication of
weakness, or other abnormal behavior at-
tributable to loss of the spear, while striking
the trolled bait or during the ensuing battle.

RECORDED FEEDING AND BAIT-SEIZING
HABITS

The fact that marlins can exist reasonably
well without their spears reopens the question
of how spearfish feed. Many anglers and
authors of books on angling for the large
game fishes have given accounts of spearfishes
stunning their prey and trolled fish baits with
a slashing blow, before turning to devour
them. The angling methods for these fish
have long involved a slack line arrangement
to allow the bait to lie "dead" in the water
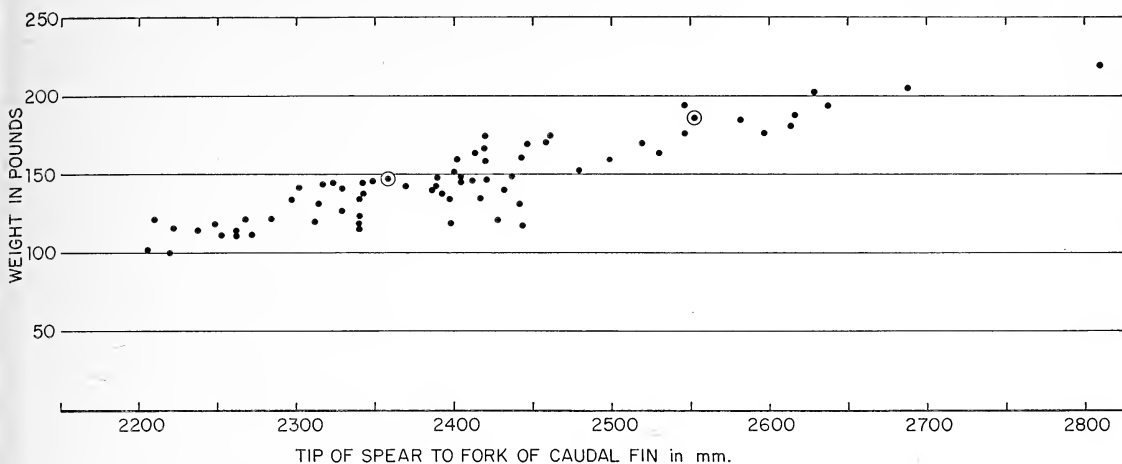following the initial rush or strike of the fish.

FIG. 3. Relation between weight and length from tip of spear to fork of caudal fin for striped marlin caught near San Diego in 1952. The two circled entries are for the two spearless fish caught that year. Their lengths are computed by adding the average length of spear from tip of mandible for other marlin of the same length behind tip of mandible. The two spearless fish are at least average weight.

According to Van Campen Heilner (1943: 108–109) almost no spearfish were taken in Florida waters before the discovery of this method by the famous Captain Bill Hatch of Miami, Florida, while experimenting with methods of taking sailfish. Heilner stated that Hatch, the father of the "Drop-back," came to the conclusion that, "When the sailfish first rushed the bait he struck it a blow with his spear to stun it and if it didn't collapse then and there, something was phoney. By immediately allowing a lot of line to run off the reel the sailfish was fooled into believing he had paralyzed his prey and would return to seize it." Prior to the use of this method the sailfish only mauled the fish being used as bait for kingfish and mackerel but could not be hooked, which may indicate that the sailfish were grasping the bait between their jaws rather than striking it with their spears and that the bait was pulled from their jaws or rejected before it could be swallowed.

It is known, of course, that marlin in particular do not always strike a blow before

FIG. 2. Striped marlin with a deformed spear. Photographed at Mazatlán, Sinaloa, México, Mar. 26, 1954, by R. L. Wisner.

taking the bait. A fast rush and grab is most frequent. A hungry fish, of course, is much less apt to toy with a bait or prey than to make haste in consuming it. Thomas and Thomas (1930: 130) cited a fish that did not attempt to stun the bait with the spear. "The marlin changed direction in his rush and, just before he reached the lure he swerved to one side, as such fish nearly always do, and seizing his prey between his jaws, whirled, splashed a trifle, and, like a ray of light as he showed his gleaming underbody, turned downward and was away." In another connection (p. 122) these authors stated: "When marlin hit a troll they do not grab it in their mouths as do other fish; rather they seize it between their upper and lower bills before swallowing, and seem to approach the lure sideways, turning it before gulping it down." Bandini (1933) lent support to this opinion by stating, "A marlin seizes the bait crossways in his mouth and swims away with it."

In contrast to the foregoing testimony, Thomas and Thomas described the feeding habits of marlin as follows (p. 121): "They feed chiefly on anchovies, sauri [sic], sardines, flying fish, and other small fry, charging into schools of these unfortunates and slashing

right and left with their bills, before turning back and leisurely picking up those they have killed or crippled." Another report by these authors (p. 136) was that: "Marlin were everywhere, scattering bait and cutting the water with their fins and tails .... Terrified patches of bait skittered across the water endeavoring to elude their pursuers who slashed relentlessly."

Voss (1956) has contributed the following information. "How well the sailfish uses this weapon I discovered one calm winter day off Stuart, Florida, when we backed our boat into a school feeding on minnows. The sailfish circled slowly, sails half raised, herding their prey tighter and tighter. First one and then another broke from the circle and swam through the milling prey, thrashing right and left with their bills. Then the predators would submerge and lazily eat the dead and stunned minnows as they drifted down."

It is, of course, possible that a difference exists in the method of capturing trolled baits and free-swimming prey, even though the spearfishes may be facile in each method. One must give complete credence to such observations as made by Voss. It is evident that on occasion, abnormal though it may be, the spear is used to obtain food by thrashing. However, the mass of observations indicate this to be a rather infrequently employed method. The following observations from the field and from studies of stomach contents shed considerable light on the matter.

In examining the stomach contents of many marlin, the author has at times noted that the heads and pectoral regions of some of the less digested specimens had been severely damaged on both sides, presumably as a result of having been crushed between jaws. Along the same line Thomas and Thomas (op. cit., p. 124) stated that "the bills [upper and lower jaws] of a marlin leave two distinct depressions on a small fish just behind the gills." These observations indicate that, at least at times, the struggling prey is seized so as to kill it, or to hold it firmly preparatory to swallowing

it. The observations also indicate that in such situations the spear is not used to obtain food. If the prey had been killed or stunned or so injured as to prevent escape the marlin would not have needed to crush the prey before swallowing it.

That marlin can feed without the use of the spear is demonstrated by the following statement by Miss Francesca LaMonte of the International Game Fish Association (quoted by Hubbs and Wisner, 1953): "Dr. D. G. Maitland of Sydney, Australia, has recently written us as follows: 'It may interest you to know that I have actually watched a pair of Black Marlin feeding upon *Physalia*, like huge Rainbow Trout taking flies, and absolutely ignoring a most tempting looking mackerel bait drifting in front of their noses.'"

That prey much larger than the small coelenterate of the genus *Physalia* may be captured without obvious use of the spear is indicated by another observation. During preliminary studies of the food of striped marlin in the San Diego area in 1952, a young blue shark, *Prionace glauca* (Linnaeus), a little longer than 24 inches, was found in the stomach of a 205-pound marlin. This shark, which had been recently ingested bore no marks of a blow or thrust of the spear. A roughening of its skin over rather broad areas could have been produced by the sandpapery jaws of the marlin as it grasped and held the struggling shark. A blow, or blows, of sufficient force to kill or stun the notoriously hard-to-subdue shark would almost certainly have left identifiable marks on the body.

Still another indication of feeding that certainly would not call for use of the spear was encountered by the author while examining striped marlin stomach contents at Mazatlán, Sinaloa, México, in March, 1954. Both marlin and sailfish were feeding on a species of argonaut. Such a relatively slow-moving mollusk would be as easily captured as *Physalia* and would require not even the lightest tap from a spear.

Until very recently none of the studies of the food habits of marlin has disclosed any ingested fish that show the marks of having been slashed by or impaled on the spear. Hubbs and Wisner (1953), for example, found no evidence of fish having been damaged by the spear. A more definitive study of stomach contents for the 1952 and 1954 seasons in San Diego has substantiated these findings. Miss Francesca LaMonte (correspondence) states: "In no case have I ever seen anything that seemed to have been slashed by the spear or impaled upon it."

RECORDED USES OF THE SPEAR

The fact that the spear has been retained since possibly Upper Cretaceous, and certainly since Eocene times (Berg, 1940), indicates that it is much more of an aid than a hindrance to the fish. That the spear may, on occasion, be used to obtain food by stabbing, or as a weapon, is illustrated by the following observations. Anonymous writers (1955a, b) recorded that during a cruise into tropical waters south of Hawaii, "An interesting incident was the landing of a huge white marlin [*Istiompax marlina* (Jordan and Snyder)], estimated to have weighed around 1,500 pounds, which had in its stomach a freshly killed yellowfin tuna 5 feet in length and weighing 157 pounds. . . . The tuna had been speared clean through its body twice before being swallowed."

Another such observation from Hawaiian waters, again provided by Mr. Vernon E. Brock (correspondence), is as follows, ". . . the use of the spear to stab another fish does occasionally occur. One such observation by the skipper of the territorial research vessel was made off the Kona coast of Hawaii a number of years ago when a marlin was observed at the surface of the sea with its spear thrust through the body of a dolphin [*Coryphaena hippurus*]. The dolphin was struggling vigorously and the marlin would rear out of the water in an apparent attempt to prevent the flopping fish from working free of the spear."

Zane Grey (1926: 48) reported finding a snapper with a round hole in it in the stomach of a marlin caught in New Zealand waters. In Tahitian waters Grey (1931: 229) quoted Captain Mitchell, his fishing companion, as reporting his bonito bait rammed clear through by a marlin. Farrington (1937: 221) reported big dolphin "batted" into the air by marlin and that numbers of dolphin have been caught that had holes in them where marlin spears had pierced them.

This author has very recently studied a frigate mackerel, *Auxis* sp., and a sierra mackerel, *Scomberomorus sierra* Jordan and Starks, removed from marlin landed at Mazatlán, Sinaloa, México in March, 1954. These fish, respectively 300 and 430 mm. long, each bore the marks of a spear thrust through the midsection, respectively above and below the lateral lines. Each fish was removed by the author from undamaged, freshly caught striped marlin and wrapped and stored until studied. Unquestionably, the marks were made by spears as the holes were large and had been torn out through the dorsomedian flesh of the *Auxis*, and through the ventromedian flesh in the *Scomberomorus*. Several other fish of the same species groups and similar in body sizes bore no marks of the spear.

Gudger (*op. cit.*, pp. 271–274) cited several reports from reputable observers which indicate that battles occur between swordfish and spearfish, and between members of these two families and sharks. Broken spears have been found imbedded in the flesh of each, some obviously having been there for some time. Voss (*op. cit.*) reported catching a sailfish that had the broken bill of another sailfish projecting [through the body] on either side.

SPECULATION ON THE USES OF THE SPEAR

It seems probable that the spear is used both as an aid in food-getting and as a weapon. It is a rather moot question whether the cited stabbings and "battings" of larger fish

resulted from pugnacity, playfulness, or a desire to obtain food. The 157-pound tuna could conceivably have been regarded as an enemy by even a 1,500-pound marlin. The big dolphin would not seem to fit the enemy category although the relative sizes of prey and predator were not given. If it may be assumed that marlin customarily charge their prey to engulf it, it is then possible that the stabbings were accidental. If a spearfish is able to overtake its prey with sufficient speed to impale it, such speed should be more than adequate to permit the prey to be seized. Accidental stabbings of the smaller prey seem quite plausible if one considers the almost phenomenal accuracy required of the predator to hit and penetrate even an unsuspecting prey. In line with this view, impaling an evasive prey appears to be governed by chance. The few observations of stabbing make it seem possible that the spear may be used against the larger fishes—those not readily captured by overtaking and seizing between jaws.

The preponderance of evidence indicates the spear is not commonly used as a means of getting food. The food content studies to date have all dealt primarily with smaller forage animals. Presumably few others have been found. One must conclude that these comprise the bulk of the food of the spearfishes. As stated earlier, few indications of stabbing and none of injury by blows have been found. The prey had evidently been overtaken and engulfed by the predators. Those spearfish found with the spears missing had almost certainly employed this method of getting food.

Examination of the spear and jaws indicates that the smaller forage fish and squid, the prime components of spearfish food, could not readily be stabbed. The spear is relatively dull at the tip and is covered by minute, sharp, backward-pointing nodules for its entire length. These nodules continue to each jaw, where they become a raspy band of teeth. The roughness of the spear covering is at-tested by fishermen who almost invariably wear gloves to avoid having their hands abraded while the fish are being boated. It would be difficult indeed for the dull tip to penetrate small fish. Certainly the soft, flexible body of a squid would be extremely difficult to be impaled or to be dealt a damaging blow with so blunt a weapon. The swordfish has a smooth, laterally flattened sword of proportionately greater length than that of the spearfishes, but it is equally blunt at the tip. It is better suited as a flail but no better suited for spearing small prey. A striped marlin poorly suited for stabbing prey was observed by the author at Mazatlán, México, 1954 (Fig. 2). The curve of its spear was such that a thrust would tend to slide off a relatively small fish.

Further evidence that the spearfishes do not commonly slash with their spears is found in their skeletal make-up. The construction is not suited to free and extensive sidewise motion. The istiophorids have heavy, flat, plate-like neural and hemal spines rather than the common rodlike spines of other fishes. The neural processes are modified into broad platelike structures that extend far forward, almost reaching the middle of the preceding vertebra. The platelike hemal spines are firmly attached to the hemal processes of the neighboring vertebrae, as are the neural spines and processes. Such construction produces an exceptionally strong and inflexible, interlocking, bracing system. The vertebral column of the broadbill is less interlocked but is so fashioned as to resist greater shock from head-on encounters than is that of the spearfishes.

Nakamura (1938), who studied the skeletons of many spearfishes, concluded that "The vertebrae are most unsuited for precise movements, and sudden changes of direction are probably impossible." Furthermore, the deep and flat lateral surface of the anterior part of the body would require tremendous energy and leverage against the resistance of the water to accomplish a slashing movement

sufficiently rapid to strike a small fish fleeing for its life. Such great expenditure of energy would detract from the forward speed of the spearfish, bringing it to a virtual standstill and allowing the prey to escape with but little damage.

It is more reasonable to assume that when a spearfish charges into a school of forage fish the slashing motion observed by many fishermen is really a slight changing of direction and a grasping for the fleeing prey, the head and body describing a relatively small arc. Such a grasping motion is not to be identified with any such deliberate slashing as Voss (*op. cit.*) reported for sailfish. In his observation the prey was herded into a tight school. The speed of the predators was not mentioned. They merely swam into the closely packed school, held together by the remaining sailfish (of unreported number), and thrashed with their spears. Presumably all energy could be utilized solely to kill fish rather than be expended in pursuit.

It must be assumed that spearfish are not always able to concentrate their prey in such fashion. In a less dense and guarded school of prey, and certainly in a very scattered school, it would not be advantageous to merely slash. It is entirely possible that the normal procedure is to charge into the school rapidly snapping the jaws and reaching, within physical limits, for as much prey as possible, with the result that many of the small fish are killed or wounded before the school scatters. Any effective striking with the spear that may occur is probably a secondary and fortuitous event. After the school has scattered the spearfish would likely see the wounded or killed fish and would return to ingest them.

These large fishes are obviously built more for forward speed than for marked agility. It is entirely within reason to assume that a spearfish can readily overtake any of the forage fishes or squid, which constitute the bulk of its food, and most of the larger fishes. A conservative estimate of their speed is at least

25 miles per hour and bursts of much greater speed are probable. A hooked sailfish was clocked at 100 yards in three seconds, or approximately 68 miles per hour (Walford, 1937).

The enormous speed and power of spearfish are dramatically attested by the puncturing of ship hulls. Gudger (1940) reported, with documentation and photographs, many spears found in wooden and copper-clad hulls of vessels. Some of these had penetrated fantastic thicknesses of timber and had broken off to furnish irrefutable evidence of speed and power. One remarkable example follows: "The spear was found to have penetrated through the copper sheathing, an inch board sheathing, a three inch hard wood plank, the solid white oak timber of the ship 12 in. thick, through another two and a half inch hard oak ceiling-plank, and lastly had perforated the head of an oil cask, where it remained immovably fixed so that not a single drop of oil had escaped." This total of 18.5 inches through hardwood, 14.5 of it through dense oak, was accomplished by a spearfish as the recovered spear was round, unlike the flattened blade of the broadbill swordfish.

San Diego based wooden-hulled fishing vessels have at times been placed in danger of sinking by these fish. The tuna vessel "Rose Ann" (San Diego Union, 24 Oct., 1946) was struck three feet below the water line off Punta Abreojos, Baja California, and was forced to use both bilge pumps constantly to remain afloat. Subsequent investigation revealed five inches of marlin spear projecting through the hull planking. Fishermen recalled that other vessels in 1942 and 1946 had suffered the same type of damage. Another recorded ramming occurred off Ecuador, involving the tuna vessel "Renown" (San Diego Union, 22 Aug., 1948). Pumps were operated continuously during the homeward voyage. When the hull was inspected 18 inches of marlin spear was found projected through the 3-inch hull planking, forming a crack an inch wide.

There are further indications of the speed and power of marlin, and possibly of their pugnacity. Morrow (1951) reported having seen on a beach in British East Africa a bale of crude rubber that held the broken spear of a black marlin imbedded 8 or 10 inches into rubber so tough a man could not drive a spike into it with a heavy hammer. Smith (1956) reported on floating rubber bales from the African coast. As many as four spears have been found in one bale. Another bale contained 24 inches of the spear of a large black marlin embedded to a depth of 13 inches. In one bale was found the sword of a broadbill swordfish, indicating that it also charges floating objects.

The reasons for these attacks are not completely understood. Some may be the result of sheer pugnacity. However, it has long been known that fish often lie beneath floating logs, debris, ship hulls or any fairly large, slowly moving object at or near the surface. The tuna live-bait fishermen make a practice of fishing, often with considerable success, close to such objects, including the large whale shark, *Rhineodon typus* Smith. The ramming of ship hulls may well be the result of excess speed and a lack of maneuverability of the attacker as it charges to engulf fish lying under such shelter.

Gudger (*op. cit.*) supported this view with an observation by F. D. Bennett (Narrative of a Whaling Voyage Round the Globe, 1833 to 1836, London, 1840). Bennett tells of albacore [*sic*], clustering in a dense shoal under the ship, that "swam with an appearance of trepidation and watchfullness. The cause of this unusual commotion was visible in a swordfish, lurking astern, awaiting a favourable opportunity to rush upon his prey when they should be unconscious of danger or away from the protection of the ship. . . . and in the course of the day we observed him make several dashes amongst the shoal with a velocity which produced a loud rushing sound in the sea. . . . It is probable, as a precaution against the attacks of this mon-

ster, that albacore, and some other tropical shoal fish, attach themselves to ships, . . . , the close vicinity of a large body being sufficient to deter the swordfish from making his usual impetuous thrusts amidst the shoal; the which, when rashly attempted, have given rise to the appearance of the broken rostra of these fish impacted in the planks of ships, . . . as is not unfrequently noticed." Although the name "swordfish" is used it may also have been a member of the round-speared Istiophoridae, as all were termed swordfish until recent years.

Certainly no flailing at prey could have resulted in such penetrations of hulls as recorded. The angle of incidence of spear and hull would either have deflected the spear or have caused only slight penetration. Also, if the spearfish had concentrated on a side-to-side motion, the greater portion of the total energy would have been expended in this action. The forward speed would have been correspondingly reduced, so as to lessen the depth of penetration, regardless of the angle of incidence. Only a straight-forward charge resulting from pugnacity or an attempt to capture prey could result in such penetrations.

The biological significance of the spear may well be an adaptation for the great speed and power of these large fish, as well as a weapon of defense or attack. I am indebted to John D. Isaacs and Carl L. Hubbs for the following suggestions. A terminally opening mouth would create enormous drag and would push in front a mass of water at a similar speed, so that a spurt of the intended prey would lead it to safety. If the mouth were terminal the common mode of ingestion by suction due to a sudden spreading of the gill covers as the mouth is opened would probably be difficult and perhaps dangerous at extreme speeds. On the other hand the projecting and tapered spear would scarcely impede the flow of water past the narrowly triangular mouth on the lower surface of the base of the beak. A sudden snapping of the sharply pointed inferior mandible would induce minimal drag and would be effective in

grasping prey. If the spear is of use in feeding, it is probably of most value in permitting high speeds to be attained by the feeding fish.

It may be argued that the tunas and porpoises are also rapid swimmers yet have terminally opening mouths. However, they too are well streamlined and have relatively narrow snouts that no doubt induce minimal drag at high speeds. Indeed, their spearless heads may be considered analagous to those of spearfish without spears. There is little doubt but that the tunas and porpoises rely on speed to capture prey.

SUMMARY AND CONCLUSIONS

It is concluded that the spearfishes rely primarily on speed to overtake and engulf their food. This circumstance explains why spearless marlins are able to obtain food and to exist in competition with their undamaged fellows. The widely held belief that these fishes, marlins in particular, normally stun prey with a blow of the spear has presumably stemmed from fishermen watching fish turn slightly to grasp the bait between jaws or to engulf it, during which action the spear performs a lateral motion readily interpretable as a slash or blow. The several instances of stabbings of prey may well have resulted from the high speed of the predator and escape attempts of the prey, the spear point inadvertently striking the prey. There is little to indicate that most stabbings are intentional. In the face of preponderant evidence that most of the prey is not stabbed, one must, for the present, accept the probability that such spear penetrations are quite accidental.

Further evidence that these fishes rely on speed to overtake prey are the numerous accounts of the ramming of ship hulls and floating objects. It seems logical to assume that many such rammings result when spearfishes charge prey lying under these vessels and either fail to see the hull or misjudge the distance between prey and hull. The depths of penetration strongly indicate that the spearfish was not using its spear as a flail to obtain food. Such penetrations of objects could have resulted only from a straight-forward charge, either to seize the prey lying underneath or to battle a fancied enemy.

The restrictions in rapid lateral movement imposed by the highly integrated and reinforced vertebral column render it highly improbable that such fishes normally kill or stun prey by slashing with their spears, particularly when in pursuit of fleeing prey. The roughened surface of the spear and its relatively blunt tip preclude the possibility of stabbing the smaller fishes and the squid, which comprise the major food items of the spearfishes.

In whatever way it is used, the spear presumably serves a hydrodynamic function, increasing the speed of these large fishes. In feeding it presumably does more. The form of the spear and of the adjacent parts of the head seem well fitted to avoid drag, escape of prey, and possible injury at high speeds when the mouth is opened. A rapid water flow is induced past the mouth region, and the mouth appears to be so formed as to present minimal resistance when closed and but slight resistance when opened to seize prey.

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Magnetic Spherules in Deep-sea Deposits

Hans Pettersson and Kurt Fredriksson[1]

Few of the components entering into the sediments covering the ocean floor have attracted so much attention as the magnetic spherules first described in 1876 by Sir John Murray. Struck by the resemblance of their surface structure to that of iron meteorites, Murray called them "cosmic spherules." The number he was able to extract from one quart of the deposit, by means of a small magnet, varied from 20 to 30 in samples of Red Clay, whereas in the same quantity of Globigerina Ooze only one or two were found (Murray, 1876).

Together with A. F. Renard, Murray later published (1897) a more detailed description of the spherules in volume 4 of the "Challenger" Reports, *Deep Sea Deposits*. The higher numbers found in the Red Clay are ascribed to its much lower rate of sedimentation.

Hoping that the method of counting the magnetic spherules present in different kinds of deposits may afford a solution to the difficult problem of determining the rate of deep-sea sedimentation, one of us decided to include in the equipment of the Swedish Deep-sea Expedition (1947–48) special corers of wider diameter than those otherwise used from the "Albatross," viz., with an internal diameter of 90 mm. instead of the usual 46 mm. For various technical reasons this wide-bore corer was not used until we reached the western Pacific Ocean (Pettersson, 1956). Owing to the higher resistance offered by the

sediment to a thick coring tube, and owing to the necessity of avoiding too heavy a strain on the steel cable used when coring, the length of the thick corer had to be limited to only 6 metres, as compared to the 15 to 20 metres of the narrower coring tubes. The length of the thick cores raised was, therefore, in general only 5 to 5½ metres. On the other hand, from a section taken from a thick core about four times more material was obtained than from a narrow core of the same length. In all, a dozen of such thick cores were raised from the cruise with the "Albatross" through three oceans.

Owing to more pressing work on other material collected during the cruise, the working up of the thick cores for magnetic spherules had to be postponed for several years after our return from the expedition. However, in the meanwhile a young technician, T. Laevastu, then in the employ of the Oceanographic Institute in Göteborg, was charged with carrying out preliminary extraction experiments using parts of a narrower core of Red Clay raised from the central Pacific Ocean. For this work an electromagnetic extractor of high efficiency had been obtained from the well-known New York firm of Frantz. Portions of the sediment suspended in water were passed through this extractor. Already in the preliminary experiments with this instrument its great superiority over the primitive method for extraction used by Murray was apparent, the number of spherules extracted from 1 kg. of Red Clay varying between a few hundred and a couple of thousands. Attempts to estimate the efficiency of the method were also carried out by adding to sediment already extracted a counted number of artificial magnetic spherules, made from iron wire with the oxygen flame, having slightly larger dimensions though than the

71

natural magnetic spherules found in the sediment. The yield was found to exceed 90 per cent. The results from the preliminary investigation, including a graph showing the size-distribution of the natural spherules, has been published by Laevastu together with Prof. O. Mellis of Stockholm (1955), who had given him valuable help in the microscopical study of the spherules.

Our first objective when starting our work in November, 1954, was to perfect the method of extraction, involving also the preparation of the sediment samples obtained from the cores. The details of this preparatory work, carried out in the Oceanographic Institute with the excellent help of Mrs. Karin Romlin, technical assistant, will be given in a future publication by one of us. It will suffice to mention here that we found it necessary to pass an aqeous suspension of a quantity of the sediment, weighing from 200 to 700 grams (with the narrow corer the sample weight varied between 20 and 300 gr.), at least three times through the extractor. From the magnetic particles thus obtained, which comprised also a large proportion of nonspherical particles of terrestrial origin (largely magnetite), those with strong magnetic properties were separated out by means of a small electromagnet and then passed through sieves of different mesh, separating out the three size-classes: coarser than 60 μ, 60 μ to 30 μ, and less than 30 μ in diameter (see Figs. 1 and 2). The products from this fractionation were then mounted between glass discs in a manner suitable for counting under the microscope. This latter operation was made by one of us in Stockholm, more recently assisted by fil. kand M. Nilsson.

The operations required for a detailed examination of the spherules, like polishing, X-ray examination, etc., were carried out in the Mineralogical Institution of Stockholms Högskola (Fredriksson, 1956). To its director, Professor S. Gavelin, we are much obliged for his support and advice. We are also in-debted to Professor F. Hecht of the II Chem-isches Institut der Universität Wien, for kindly carrying out for us micro-analyses for nickel and cobalt on some of the spherules submitted to him. His results proved nickel to be definitely present in a percentage varying between 6 per cent and 15 per cent of the iron content. Recently Dr. A. Smales at Harwell kindly investigated samples of deep-sea spherules for nickel and cobalt by means of neutron-activation in the pile.

In order to get comparable results from one sample to another, we found it advisable to concentrate the counts on black spherules of a diameter exceeding 30 μ. The spherules smaller than 30 μ are difficult to count and easy to overlook. Their contribution to the total weight of the spherules appears insignificant. Spherules of the greatest size, i.e., from 60 μ to 250 μ were also counted. Their contribution to the total number of spherules is not great, but, owing to their large size, their contribution to the total weight is considerable.

The following table gives a survey of the cores from which we have extracted and counted spherules.

COMMENTS

CORE 71. This core is of special interest, as it was raised from the vicinity of Challenger Station 274 (S 07° 25′ W 151° 15′) where the depth was 2,750 fathoms or 5,030 m. The sediment in the surface has been characterized by Murray and Renard (1897) as Radiolarian Ooze with 3.89 per cent $CaCO_3$. The core raised from the "Albatross" has a total length of nearly 10 m., from which sections of 26 to 76 cm. in length were taken.

The number of spherules per kg. of sediment, free from salts and lime, varied from a maximum of 1,400 near the surface to a minimum of slightly more than 100 per kg. A second maximum of 600 spherules per kg. appears at the 10 metre level. Control counts made on halves of the section, cut lengthwise, gave fairly large variations in the proportion

TABLE 1

CORE NO.	DIAM. OF CORE, MM.	LENGTH OF CORE IN METERS	LATITUDE	LONGITUDE	DEPTH IN METERS	NUMBER OF SAMPLES
71	46	10.0	S 7°38′	W 152°53′	4990	16
90	90	5.2	S 3°21′	E 174°12′	4830	49
90 B	26	0.3	S 3°21′	E 174°12′	4830	1
92	90	5.2	S 1°20′	E 167°23′	3960	25
133	90	3.3	S 11°33′	E 91°26′	5200	18
187	46	9.5	N 33°59′	E 31°02′	2500	16
17	46		N 43°28′	E 7°22′	2030	1*
18	46		N 41°29′	E 5°51′	2680	1*
87	46		N 2°23′	W 173°50′	5560	1*
89	46		S 2°48′	W 178°57′	5480	1*

* Separate sample from the surface.

of 1:2. The average number of spherules per kg. for the whole core is about 300 (see the curve in Fig. 3).

According to radium measurements, made by Kröll (1955), in the sediment where cores 71 and 72 were taken, the rate of sedimentation is taken to be between 1 and 2 mm. in 1,000 years.

CORE 72. This core was raised from the immediate vicinity of Core 71, where the sediment had the same character. Its uppermost 3 metres, out of a total length of 14 metres, have been examined for spherules by Laevastu and Mellis (4). In Figure 4 the results from their counts are reproduced from their original paper. In Figure 3 the number of spherules is set out for the same levels in which Core 71 has been investigated by us. The figures, however, have been reduced to 50 per cent to be in conformity with our counts, since Laevastu and Mellis included spherules from diameters 10 μ upwards in their counts, whereas our counts in Core 71 are limited to diameters of from 30 μ upwards. According to Laevastu and Mellis the spherules of less than 30 μ in diameter made up less than one half of the total number.

CORE 90. This is a thick core, 90 mm. in diameter. Its total length is, therefore, very moderate, or only 5 metres. In its upper part the content of lime is low, less than 1 per cent. Below the 190 cm. level the content of carbonates increases abruptly to about 30 per cent, rising still further down to more than

80 per cent. The number of spherules varies greatly. From about 3,300 per kg. near the surface, a maximum of 5,000 is reached between 80 and 90 cm. Below the 110 cm. level the number of spherules per kg. of salt- and carbonate-free sediment is less than 1,000 (minimum 140), with the exception of a secondary maximum of 1,300 in a depth of about 280 cm.

Two parallel series of samples from this core were extracted. The results obtained from the first five samples in the first series (see full drawn curve in Fig. 5) were much lower than those from the second series. This is probably due to the fact that the technique of extraction had not been fully developed at that time, so that a certain number of the spherules may have become crushed in the extractor and thus escaped the counting.

In certain samples it proved very difficult to distinguish between different types of spherules, of which the black shiny ones were primarily counted. This difficulty may explain the strong variations found by control counts from identical levels, especially as regards the sample between 63 and 80 cm. In the diagram in Figure 5 these variations are indicated by horizontal lines, uniting the highest and the lowest values found at the level in question.

CORE 90 B. This was a narrow "pilot core" taken from the same vicinity as Core 90. The amounts of spherules in the lime-free portions in the uppermost 4–12 cm. and 0–6.5 cm. of Cores 90 B and 90 respectively were found to
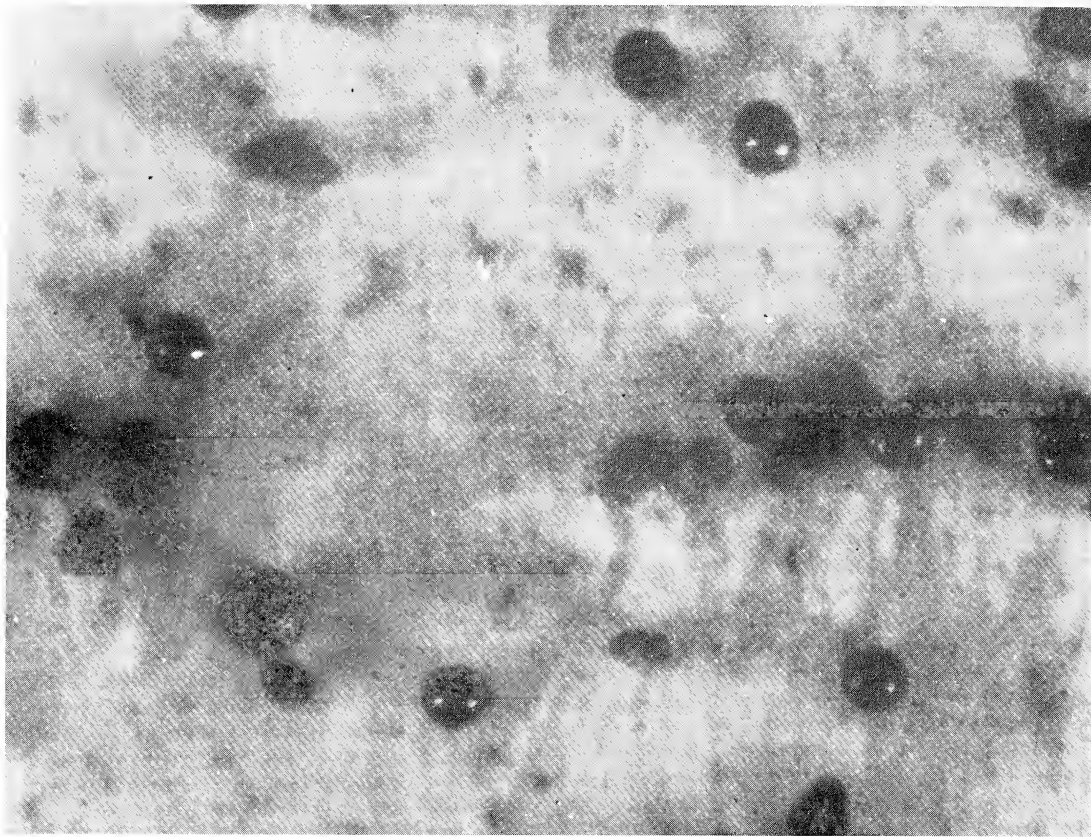
Fig. 1. Spherules from Core 90, about 30 to 60 microns in diameter.

be practically the same. The carbonate content was, however, much higher in the uppermost part of Core 90 B, viz., 56 per cent as compared with the corresponding 0–6.5 cm. of Core 90.

CORE 92. This core, raised from a depth of nearly 4,000 metres close to the Equator, is also one of large diameter (90 mm.) with a length of only 5 metres. The sediment is a calcareous ooze, its content of $CaCO_3$ varying between 71 and 82 per cent. The uppermost 64 cm. of the core were missing, having been lost in transport. The rate of sedimentation can only be tentatively estimated at 50 mm. in 1,000 years.

The number of spherules extracted was very low. Recalculated to 1 kg. of lime- and salt-free sediment, the numbers varied from 0 in a depth of 201–217 cm. to slightly over 200 between 64–81 cm., 231–248 cm. and 275–293 cm. The average for the whole core was 80 spherules per kg. of sediment. (See diagram in Figure 6.)

CORE 133. This core, the only thick core (90 mm.) raised from the central part of the Indian Ocean at a depth of 5,200 m., had a total length of 326 cm., from which the uppermost 3 cm. were missing. Down to a depth of 200 cm. below the top of the core it had a moderately high content of $CaCO_3$, between 14 and 40 per cent, whereas in the lower parts of the core the lime content was only between 5 and 10 per cent, especially near the lower end where it varied over 45 cm. between 5 and 5.6 per cent. The number of cosmic spherules extracted from the uppermost 3–18 cm. was high, viz., nearly 700 per kg., whereas in the lower parts, at depths between 50 and
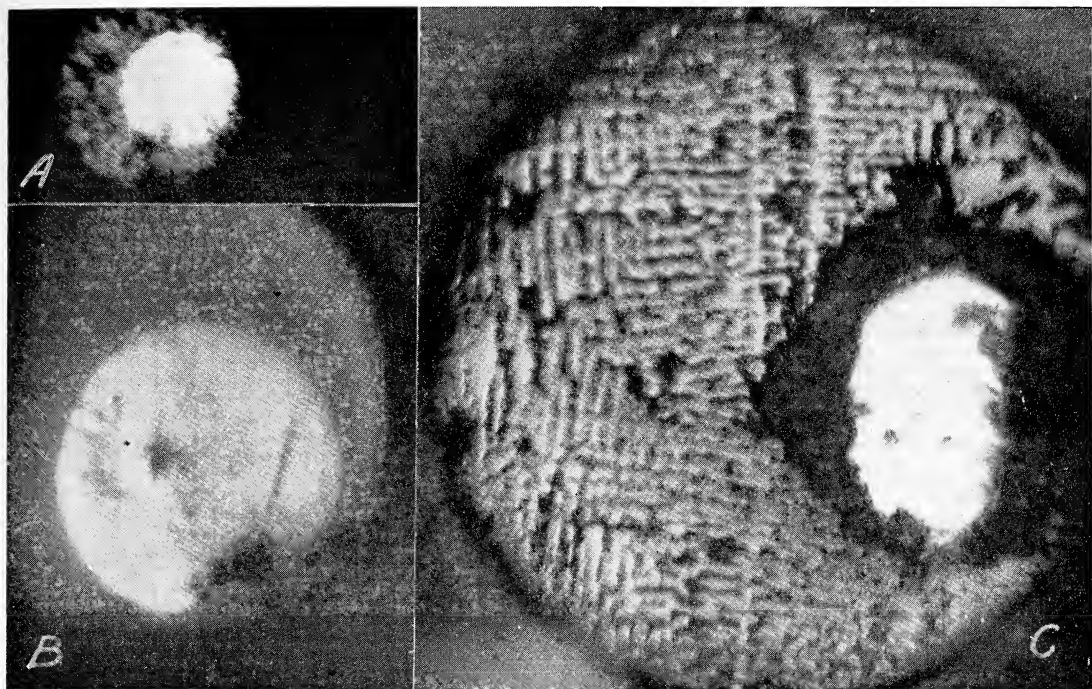
FIG. 2. Polished sections of black spherules. A, spherule from Core 71, about one meter below the sediment surface. Magnetite, gray, with a metallic nucleus, white. Diameter of spherule, 30 microns. B, spherule from the Atlantic Ocean, about 25 cm. below the sediment surface. Same type as A, with imperfect polish. Diameter of spherule, about 80 microns. C, spherule from the same sample as A. Magnetite, gray, metallic nucleus, white. Diameter, 120 microns.

220 cm., the numbers were low, rising again to somewhat higher values below 220 cm. The average number for the whole core was 130 spherules per kg., whereas between 52 and 220 cm. it was only 30, compared to the average for the uppermost 50 cm. of 500 per kg. (Fig. 7).

To ascribe these very remarkable variations in the numbers of the spherules only, or even mainly, to changes in the rate of sedimentation seems unwarranted. That even in the uppermost layers the rate of sedimentation was higher than in the central Pacific Ocean is indicated by radium measurements in a neighbouring short pilot core, Number 133 B, which contained on an average 11 units of the 12th decimal place of Ragr/gr, compared to from 40 to 50 units in Red Clay from the central Pacific. Thus the rate of sedimentation can be estimated for the upper parts of Core 133 at 10 mm. in 1,000 years.

CORE 187. This core, raised from a depth of 2,500 metres in the eastern Mediterranean southwest of Cyprus, was a narrow one and had a total length of 9½ metres. Hence fairly long sections of 30 to 70 cm. had to be used for extracting the spherules. The lime content was moderately high, varying between 20 and 40 per cent of $CaCO_3$. The number of spherules per kg. of lime- and salt-free sediment varied considerably along the length of the core, from 190 near the surface to an absolute maximum of 1,130 in the section 166–235 cm., declining from there, both upwards and downwards, to 5 and 10 per cent respectively of the maximum value.

At another maximum, in section 438–506 cm., 491 spherules were found per kg. of sediment. In the very lowest parts of the core, 860–950 cm., only 38 and 49 spherules respectively were found. It must, however, be emphasized that where control samples from
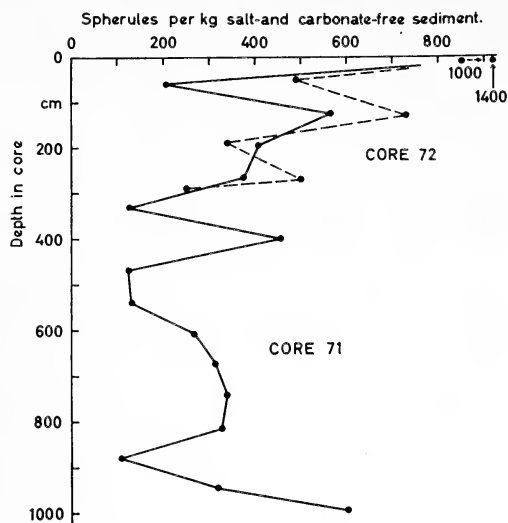
FIG. 3. Number of spherules per kg. of dry substance from Core 71.

the same levels were taken, the values varied considerably *inter se*. The average for the whole core is 190 spherules per kg.

Regarding the rate of sedimentation in this core very little is known. O. Mellis (1954), from a study of the volcanic ash horizons present in cores from the eastern Mediterranean, has identified a layer of volcanic ash in Core 187, situated at a depth of 40 cm. below the top of the core. This layer probably owes its origin to the catastrophic outbreak of the island volcano Santorin, which occurred some time between 1800 and 1500 B.C., i.e., about 3,700 years ago. This assumption would make the rate of sedimentation in the upper layers of the core about 10 cm. in 1,000 years, leaving aside possible disturbances in the sedimentation due to slumping, etc.

Regarding the two maxima found in Core 187, it should be noted that the spherules they contain were especially difficult to identify, resembling some of the samples in Core 90. The values given here must, therefore, be stated with due reserve and have only been indicated in the curve in Figure 8. Nevertheless there is little doubt that the maxima are real, even though the numerical finds are

somewhat uncertain. Attempts to find such maxima in other cores from the vicinity are at present being undertaken.

Considering the abrupt decrease in the number of spherules on both sides of the principal maximum, one is tempted to assume that at the time when the maximum occurred one or several meteoritic showers fell upon the eastern Mediterranean. An alternative explanation, that at the time when the maximum occurred there can have occurred an abnormally low rate of sedimentation, appears less probable.

It would be most interesting to investigate other cores, preferably of larger diameter, taken in the vicinity of Core 187.

MAGNETIC SPHERULES FROM THE ATMOSPHERE

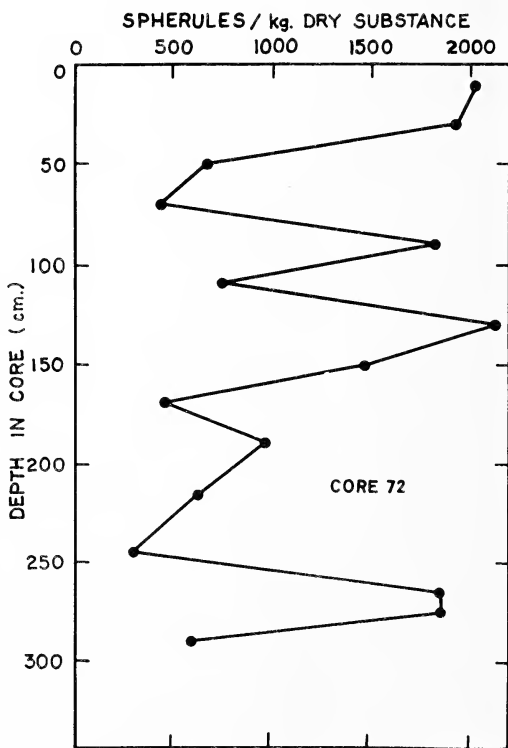The problem of finding by direct observation the amount of magnetic particles settling

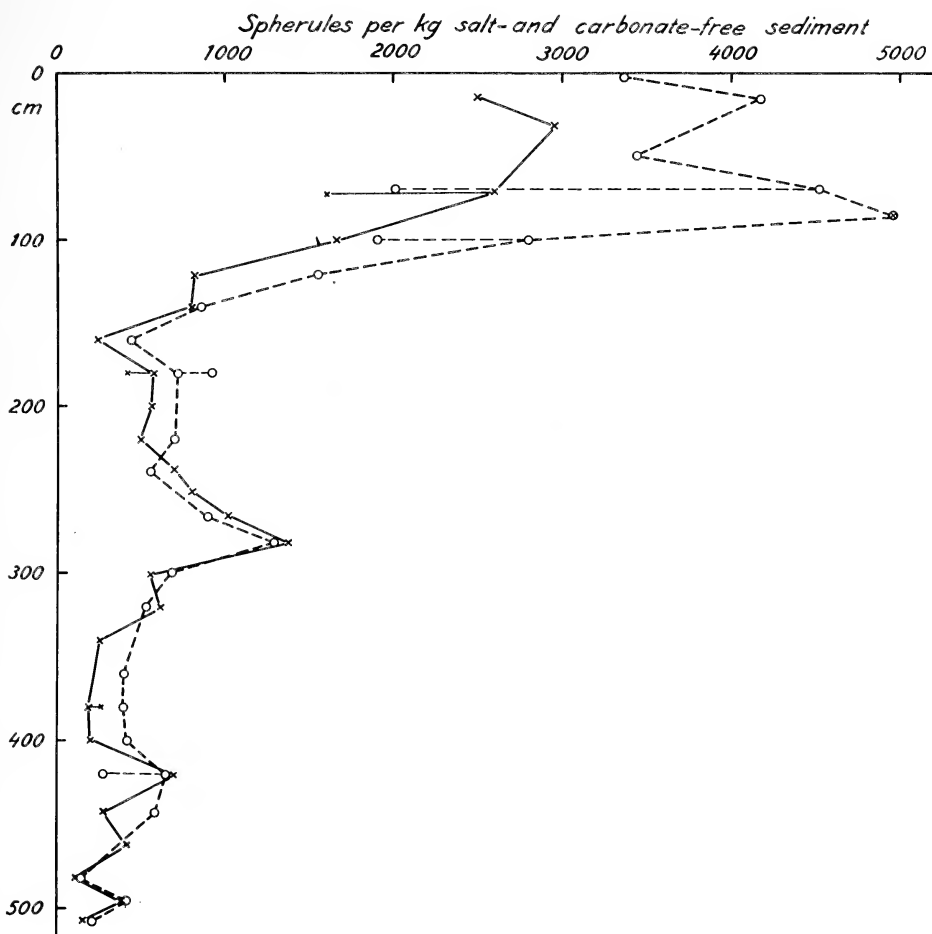FIG. 4. Number of spherules per kg. of salt- and carbonate-free sediment from Cores 71 and 72.

FIG. 5. Number of spherules per kg. of salt- and carbonate-free sediment from Core 90.

on the Earth's surface has repeatedly been attacked by various investigators, mainly in the United States of America. The method adopted has generally been that of introducing magnetic "collectors" into the water spouts carrying rainwater from extensive roofs. The number of magnetic spherules accumulated in this manner has been counted with results which are surprisingly large. Thus Warren J. Thomsen (1953) finds the weight of such magnetic spheres, from observations made at Iowa City, to correspond to a total mass of 2,000,000 tons per year for the whole Earth. Still higher values have been reported by W. D. Crozier (1955) working in New Mexico, viz., 35,000 tons per diem during

August 1955, or nearly 13 million tons for the whole year. These figures are several thousand times higher than those obtained from our counts of the spherules in deep-sea deposits. However, neither of the authors mentioned could find any trace of nickel in the magnetic spheres analyzed.

We have tried to collect magnetic spherules by means of magnetic collectors introduced into water spouts mounted at Bornö Station in the Gullmar Fjord, on the west coast of Sweden, and also from the roof of the Oceanographic Institute in Göteborg. At the latter locality we found the number of magnetic spherules collected to be very high, whereas at Bornö the number was considerably less but
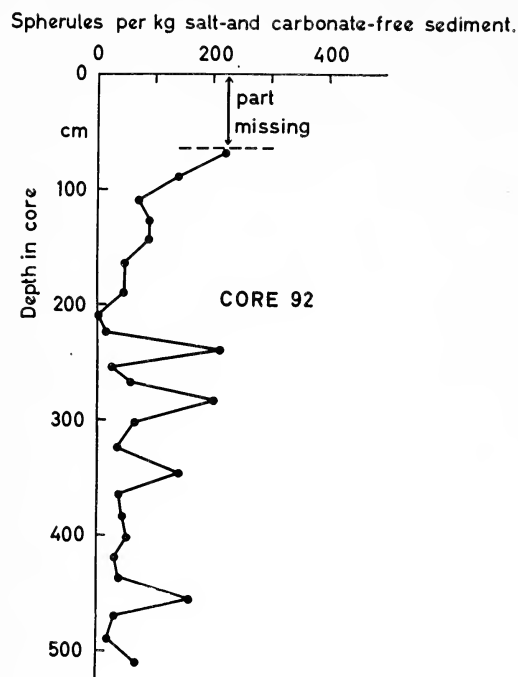
Spherules per kg salt-and carbonate-free sediment.

FIG. 6. Number of spherules per kg. of salt- and carbonate-free sediment from Core 92.

true extraterrestrial spherules settling over the ocean surface and thus complement our studies of the magnetic spherules in deep-sea deposits. Calling attention to the interesting results from the attempts at a magnetic drag over the ocean bottom from the "Galathea" Expedition, we consider the evidence in favour of the magnetic particles reported by A. Bruun and his co-workers (1955) as being largely of cosmic origin to be very strong. On the other hand this method of using a superficial collector can only be expected to bring up extraterrestrial particles of *recent* origin. Moreover, a certain risk of contamination with spurious spherules from coal- or oil-driven ships passing near the course of the "Galathea" cannot be altogether excluded. No such risks are involved when extracting magnetic spherules from undisturbed long cores provided one gets below the uppermost few centimeters of sediment. This method alone seems to allow of definite conclusions regarding the frequency of meteoritic falls and their variations in the remote past.

Quite recently the accruement of meteoritic fragments and dust to the surface of the Earth and its oceans has attracted the interest of meteorologists and climatologists.

Mainly through the work of Bowen in Australia (1953) and of his co-workers in

still higher than the numbers found in deep-sea deposits. No nickel was found to be present in these spherules.

We infer, therefore, that most of the spherules thus collected are of terrestrial origin and are artifacts from industrial plants and welding operations, which can be carried over large distances by wind.

Hoppe and Zimmerman (1954), collecting magnetic spherules at Jena and other localities in West Germany, have arrived at the same conclusion and consider it impossible to avoid such contamination in localities in or near industrial districts.

Based on these results we have planned to collect magnetic particles from the atmosphere on ocean islands situated far from any industrial plants and as remote as possible from the shipping lanes across the sea. Such measurements, which we hope to organize on Pacific Ocean islands during the Geophysical Year, may be expected to afford evidence of
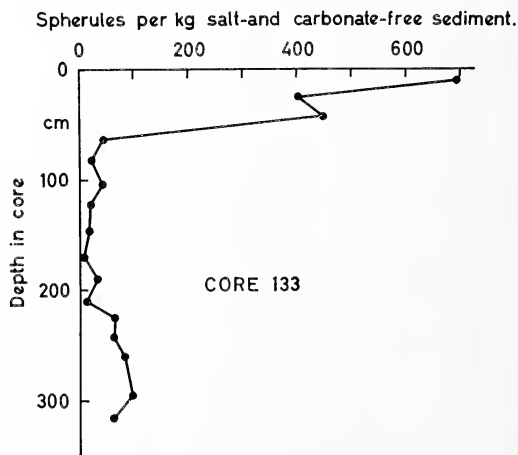
Spherules per kg salt-and carbonate-free sediment.

FIG. 7. Number of spherules per kg. of salt- and carbonate-free sediment from Core 133.

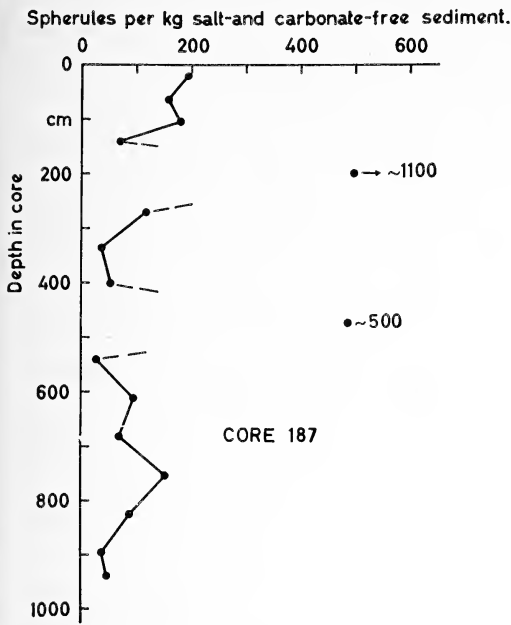Spherules per kg salt-and carbonate-free sediment.

FIG. 8. Number of spherules per kg. of salt- and carbonate-free sediment from Core 187.

different parts of the world (Bracewell, 1954) strong evidence has been produced for the influence of cosmic dust as condensation nuclei for raindrops. According to these finds there occur distinct maxima of precipitation on certain dates like January 12, 22, and 31 to February 1. These peaks of rainfall occur 29 to 30 days after the Earth has passed through meteor showers. According to Bowen the dust into which these meteors are dispersed at great heights in the atmosphere takes about 30 days to descend to the upper troposphere, where a condensation of water-drops is produced which ultimately reach the Earth as rain. Through this condensation a depletion of water vapour in the upper atmosphere is occasioned, decreasing the "green-house" effect on the radiation balance.

It has even been surmised that an abnormal increase in the incidence of meteors may give rise, by a trigger action, to a deterioration of climate and possibly release a glacial epoch.

No wonder that students of the atmosphere and its radiation balance are taking a growing interest in meteoric dust.

THE ANNUAL ACCRUEMENT OF COSMIC SPHERULES

In trying to work out the total weight of the cosmic spherules settling on to the surface of our planet the numbers of spherules found in the cores investigated can be used, converting the numbers of spherules per kg. into weights. But already this conversion from numbers into weights implies an element of uncertainty.

We have counted all spherules of a diameter exceeding 30μ and then computed the total number accruing to the Earth for one year. These values are set out in column 7 of Table 3. In converting numbers into weights we have assumed a specific weight of 5.0 and a diameter of 40μ, assuming that all the spherules belong to the size-class 30–60μ. When taking the total counted number instead of the number of the size-class 30–60μ, we add about 10 per cent as a correction for the weight of the spherules of a diameter less than 30μ. In this way the values set out in column 8 have been obtained. Finally, column 9 shows values of the total accruement of black spherules of all sizes, the value being three times higher than those in column 8. The factor 3 we obtain by considering that the number of spherules between 30 and 60μ is 8 times higher than the number of spherules exceeding 60μ in diameter. (See Table 2.) The weight of the spherules of 30–60μ is assumed to be equal to the weight of the fraction 60–125μ and 125–250μ.

TABLE 2

CORE NO.	TOTAL NUMBERS OF SPHERULES COUNTED		NUMBERS 30–60 μ
			NUMBERS 60 μ
	30–60 μ	> 60 μ	
71	349	69	5
90	2,634	303	9
92	115	23	5
133	326	29	11
187	507	58	9
	3,931	482	8

Another still greater uncertainty enters into the calculation owing to the imperfectly known rate of sedimentation. Here one has to use approximate values involving possible errors by the factor of 2 to 5, in some cases even more.

The following values worked out at the present stage of our investigation must be given, therefore, with due reservation. Compared to earlier figures given by other investigators our estimates are very moderate but are necessarily subject to an revision when more extensive investigations now pending have been carried out.

In general one gains the impression from these tables that the meteor frequency has been considerably above the average in recent times, as is also indicated in most of the frequency diagrams. However, we must emphasize the great difficulties inherent in the method of sampling. First, the surface layer may be missing, a layer which may quite well represent a sedimentation time of tens of thousands of years. Further, owing to different rates of sedimentation, a whole core like No. 187 probably represents a sedimentation time of less than 100,000 years, which corresponds only to a couple of cm. in Core 71. Hence, it is desirable to investigate a series of cores from different localities in order to arrive at really dependable values for the accruement of spherules and by this means to interrelate the results obtained from different cores.

Apart from the results given in the diagrams and in Table 3 we also have values from four other samples, two from the upper layers of two western Mediterranean (Cores 17 and 18), and two from the western Pacific Ocean (Cores 87 and 89). From Cores 17 and 18 the number of spherules per kg. lime- and salt-free sediment is 260 and 150 respectively. Assuming that the frequency of spherules is inversely proportional to the rate of sedimentation at a certain time we can, by comparison with Core 187 from the eastern Mediterranean, form an estimate of the rate of sedimentation in the western Mediterranean. We thus find a sedimentation rate of about 80 mm. in 1,000 years for Core 17 and a rate of 130 mm. in 1,000 years for Core 18, which are both quite reasonable figures. For Cores 87 and 89 the numbers of spherules were 1,725 and 1,165 respectively, and through a comparison with Cores 90 and 90 B we obtain a sedimentation rate of 6 and 8 mm. respectively in 1,000 years. These figures are three to four times higher than those found by Kröll (1955) from radium measurements. However, we do not know how far the uppermost samples in different cores represent the same span of time.

SUMMARY

The present paper gives the results from a study of the number of "cosmic spherules" present in sediment cores obtained from great depths in different parts of the ocean.

TABLE 3

| | | | | | | ANNUAL ACCRUEMENT OF BLACK SPHERULES | | |
Core No.	Depth in cm.	Rate of sedimentation mm/1000 y	CaCO$_3$ per cent	Span of time in years	Number of diam. > 30 per kg.	Number (> 30 μ) (10^{15})	Weight in tons (< 60 μ)	Total weight in tons
187	0–39	100	35	0?– 3,700	190	4.7	790	2,400
90	0–6.5	3	1	0?–20,000	3,350	1.6	265	800
90 B	4–12	6	56	7,000–20,000	3,350	1.6	270	800
92	64–81*	50	76	13,000–16,000	220	1.1	190	600
133	3–18	10	15	3,000–18,000	700	1.0	160	500
71	0–26	1.5	1	0?–200,000	1,400	0.31	60	175
72	0–300	—	—	—	—	—	—	125†

* Section 0-64 cm. lost in transport.
† According to Laevastu and Mellis.

The number of such spherules obtained by means of a powerful electromagnetic extractor is tens of times greater than the numbers found by Sir John Murray and A. F. Renard by more primitive means.

Spherules in considerable numbers are found also in depths of several metres below the sediment surface, i.e., in sediments already deposited in Tertiary Time. This definitely refutes the hypothesis that meteoritic falls, from which the spherules are assumed to be derived, have been limited to a relatively recent past, the last 25,000 years.

On the other hand there are strong indications that the frequency of such spherules deposited in recent times, say in the last few thousand years, has been higher than in a more remote past.

There are also indications of intermediate maxima which may correspond to a greater frequency of meteoritic falls during certain times covered by our material. A systematic correlation of such maxima *inter se* has not been made.

Comparing the frequency of spherules found in recent times, i.e., near the surface, in certain cores affords means of estimating the approximate rates of sedimentation.

Converting the number of spherules found per kg. of sediment into weights makes it possible to estimate the total accruement of spherules to the whole Earth, the results being a moderate figure of 2,400 metric tons annually (with a possible rise to 5,000 tons), i.e., only a small fraction of figures obtained by earlier investigators from the number of magnetic spherules collected from the atmosphere. Means of obtaining more reliable figures for such spherules by establishing collection stations on mid-ocean islands are indicated.

In cases where the number of spherules from deep-sea cores have been analysed for iron, nickel, and cobalt, the presence of nickel has given a definite proof of the cosmic origin of the deep-sea spherules.

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Lord Howe Island, a Riddle of the Pacific

S. J. Paramonov[1]

THE RIDDLE of the origin and natural history of Lord Howe Island is not yet solved and the progress of our knowledge only shows us that the problem is more complicated than we can suppose. The fact is that the island, being only 7 miles long and half a mile in width, has quite a strange flora and fauna. They are not an accidental mixture of introduced species or of very widely spread elements, but consist of a number of endemic forms of which the relationships are not quite clear. Not only the presence of some families and genera is interesting but also the absence of others.

Lord Howe Island is situated only 300 miles from Port Macquarie and 420 miles from Sydney (Fig. 1), but the basic flora is quite different from that of the mainland of Australia. Neither eucalypts nor acacias are represented in its flora, nor parrots or magpies in its fauna. Norfolk Island is also not very far from Lord Howe Island (about 450 miles), but the araucarias, so typical of Norfolk Island, are quite absent on Lord Howe Island, although there are some beautiful specimens growing near homes as introduced trees. The typical elements of New Zealand are also practically absent on Lord Howe Island. The flora and fauna of Lord Howe Island are very specific, but where did their elements come from, if they are different from the countries westward, northward, and southward of Lord Howe Island?

Our knowledge of the flora and fauna of Lord Howe Island is very poor. We have not enough material for generalisation, although some interesting facts are known. Therefore, it will be wise to approach the problem only little by little by describing and analysing different groups of animals or plants. It will be useful to concentrate our attention on the problem not only in its details, but also as a whole. It seems to be that nobody yet has been especially concerned with this problem, but for the history of the Pacific it is doubtless of very great importance. In order to understand the fauna and flora it is necessary always to have in mind the following facts:

1. On Lord Howe Island are growing four different species of palms, all endemic (Figs. 2, 4). That gives us a reason to think that the flora of the island is basically a tropical one. We cannot expect the development of four species of palms in quite recent time, so that it is quite evident that a mild climate has existed on the island for a very long time, and the fauna also must have developed the elements characteristic of a subtropical or tropical origin.

2. There are two mountains on the island (2,500 ft. and 2,800 ft.) which can give a place for development of the elements of a flora and fauna typical of a more temperate climate. (See Fig. 3.)

3. Apart from bats, mammals are absent from the island, nor are there fossils evident. There are only rats and mice, introduced by man. The rats have played an extremely important part in the impoverishment of the fauna. They caused the extinction of not only
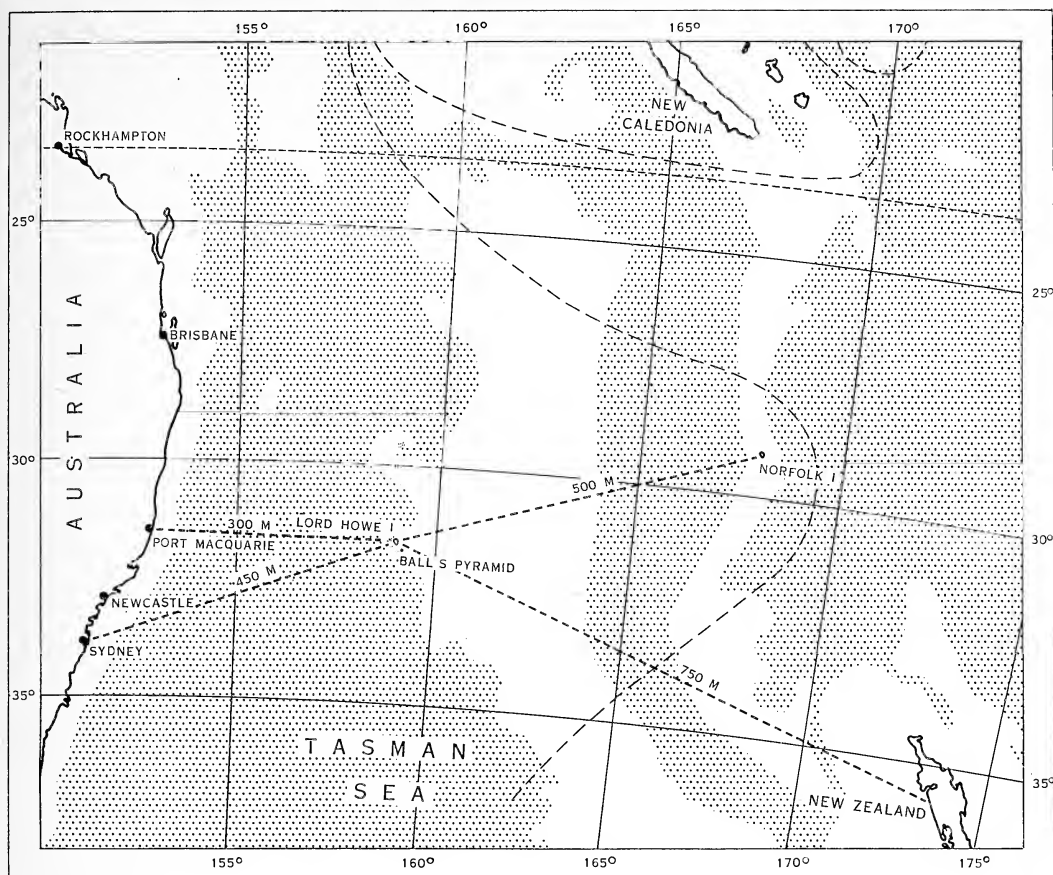
FIG. 1. Map showing position of Lord Howe Island. Latitude, 30° 33′ S., Longitude, 150° 5′ E.

some endemic birds but also of one species on insect, *Carabidion australe*, a phasmid.

4. The endemism of some elements of fauna, for example, of birds is very great, not only among the existing species but also in those recently extinct, some of which were completely restricted to the island.

5. Characteristic also is the absence of some Reptilia: snakes are quite absent, fresh water Chelonias also. There are recorded only three species of lizards. Amphibia are quite absent. An extinct turtle (probably a sea species)— *Meiolania platyceps*—was not rare on Lord Howe Island. Of the other three species of this genus, one, *M. oweni*, was found at Darling Downs, Queensland; a second, *M. mackayi*, was found on the small Walpole Island (about 100 miles south east of New

Caledonia); and the third, *M. argentina*, in Patagonia. *Meiolania platyceps* became extinct rather recently. (Anderson, 1925, 1926.)

6. There are data that various species of plants and animals arrived from time to time on the island, but later disappeared as a result of unfavourable conditions on the island, or from accidental causes, because the island is comparatively very small and the number of new immigrants usually is not so high as to resist occasional destruction.

7. The endemism on Lord Howe Island can be of two kinds: neoendemism and paleo-endemism. The neoendemism can be very new, i.e., the species can be created in comparatively very short time: a flock of migrant birds can reach the island and produce a population with more narrow limits of char-
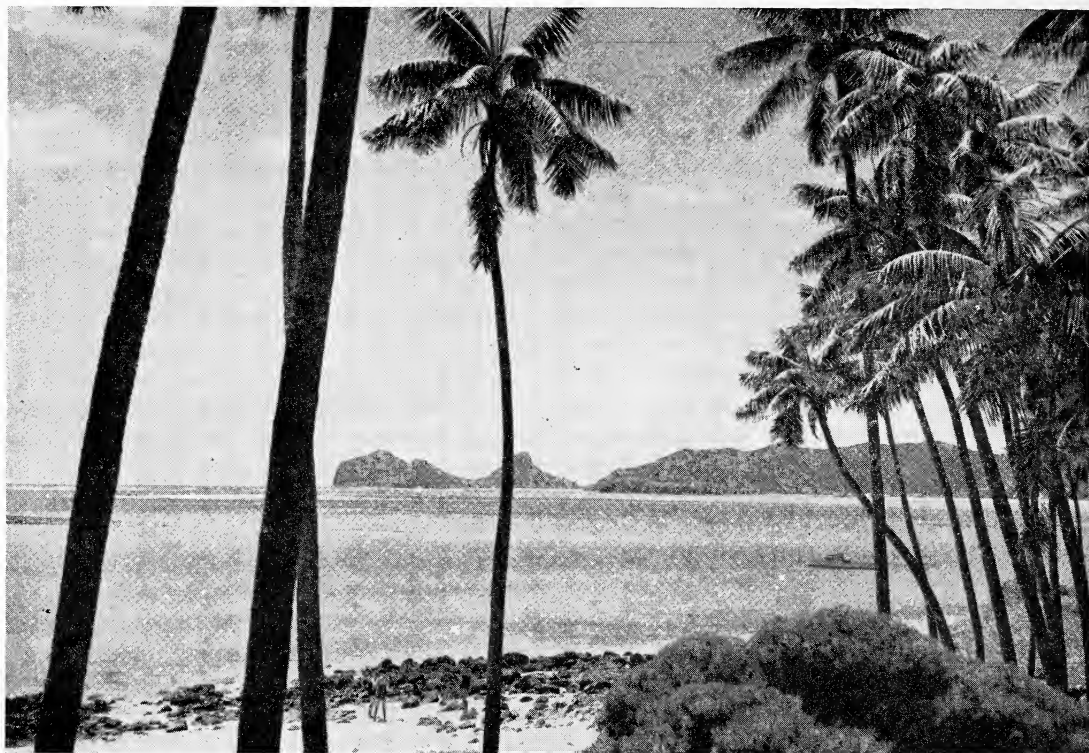
FIG. 2. A view across the lagoon, from the foot of Mt. Lidgbird, showing sands and coral rocks of the seashore. On the horizon is Mt. Eliza with its toothlike form. Photo by Miss Z. Liepa.

acters than the ancestral one. In a series of generations, which may be very small, a new species can evolve, distinct from the ancestral form but practically the same, being only impoverished in its genes (characters). This sort of endemism is of no interest to us. Only paleoendemism can give us solid data about the past of the island and its natural history.

8. Paleontological data about Lord Howe Island are very scarce because, first of all, no one has concerned himself with this matter, and second, the soils are not favourable for the preservation of fossils. The soils of the island are of two sorts: old coral reefs, which cannot contain the land fauna or contain only their occasional remnants; and volcanic soils or derivatives of them. The latter are situated very high on the island and are practically unexplored. It is possible that some bones of extinct birds, etc., could have been preserved by volcanic soils as result of a fall of rock, but nobody has been interested in their discovery.

9. The absence of some groups, families, etc., is a very complicated problem. First, it could be only lack of material, because nobody has systematically collected during a whole year on the island. Second, these groups may have been present but now are extinct owing to the influence of different conditions: the influence of man and his domesticated or semidomesticated animals, the introduction of stronger rivals, or a change of climate, all of which would have the stronger effect. Also their rarity could be caused by some too small biological niches on the island, etc. In this regard it is interesting to record the absence of such common fly families as Tabanidae, Nemestrinidae, Apioceridae, subfamily Asilinae, Coelopidae, etc.
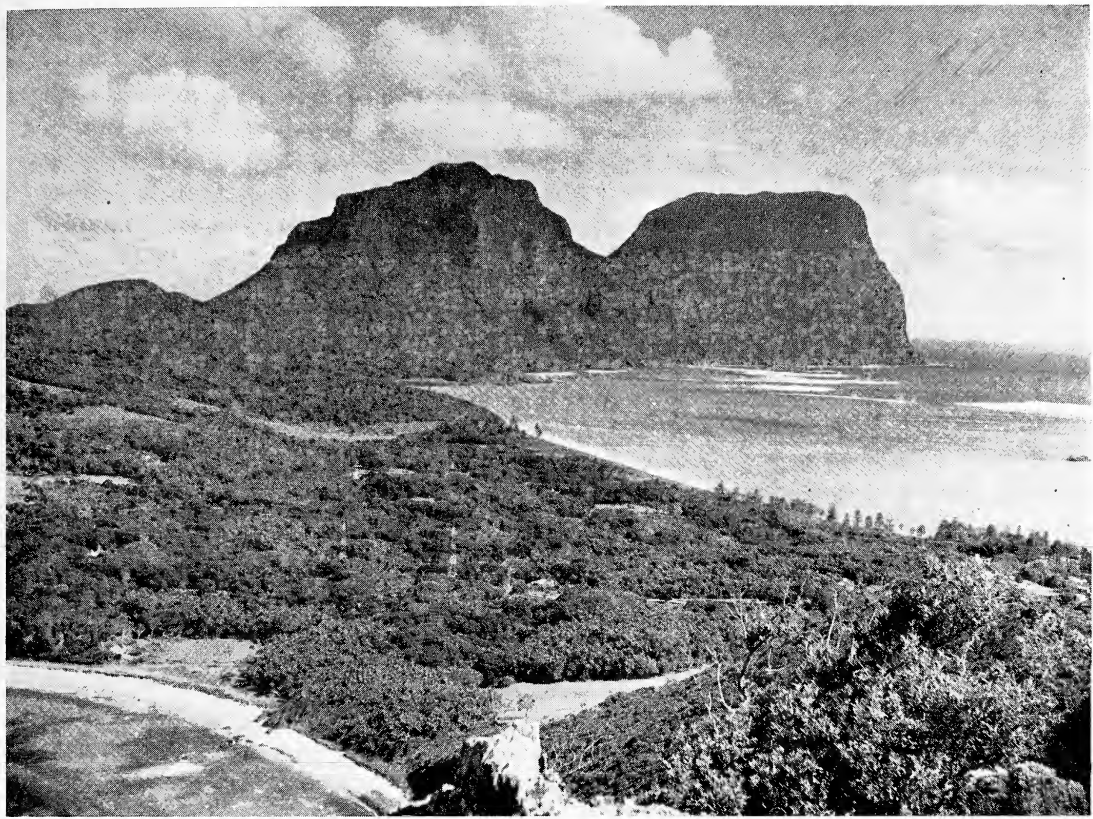
10. Some Calliphoridae (Diptera) show

FIG. 3. A general view of Lord Howe Island from Malabar Hill. In centre, Mt. Lidgbird, at right Mt. Gower. The latter is 2,800 feet high. Photo by Miss Z. Liepa.

very interesting features in regard to their distribution: the *Calliphora hortona* group, with bright orange knobs at base of wings, so typical to New Zealand and present in Sydney area (probably introduced), are absent on the island.

Lucilia sericata Meig., a semidomesticated fly, is present in enormous numbers, but the Australian sheep blow-fly, *Lucilia cuprina* Wied., is quite absent. Very strange also is the absence of the typical forms of blow-flies of the mainland, *C. stygia* F. and *C. augur;* on Norfolk Island both species are represented, whilst on the mainland they are present literally everywhere.

11. There are some interesting caves at North Bay, but owing to the shattered condition of the rock, they are very dangerous to enter. One cave about three-quarters of a mile from the shore has been explored for about 250 yards. There are some fine stalactites and shawl formations in it, but the numerous cracks around show that there may be a great fall of rock at any time. These caves were not explored biologically, but the animals they shelter can give extremely interesting data about the origin of life on the island.

CLIMATE

In order to understand the origin and composition of the fauna of the island, it is necessary first of all to know the climate of Lord Howe Island.

Table 1 presents the data published by Russell (1895), based on eight years of meteorological observations relating only to the low parts of the island. The mountain area of the island is meteorologically unknown. It is

TABLE 1

COMPARISON OF THE CLIMATES OF SYDNEY, LORD HOWE ISLAND, AND PORT MACQUARIE

	SYDNEY	LORD HOWE ISLAND	ABOUT PORT MACQUARIE
	°F.	°F.	°F.
Mean shade temperature...................................	62.9	68.6	65.3
Highest shade temp. ever recorded on any day.................	108.5	110.7	116.0
Lowest shade temp. ever recorded on any day.................	35.9	45.0	24.0
Spring mean shade temperature............................	62.9	68.0	65.6
Summer mean shade temperature...........................	70.7	74.8	73.1
Autumn mean shade temperature...........................	64.1	69.0	66.6
Winter mean shade temperature...........................	54.0	62.4	55.7

AVERAGE MONTHLY TEMPERATURES

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
Sydney............	71.4	70.9	69.3	64.5	58.5	54.4	52.5	55.0	58.7	63.3	66.6	69.7	62.9
L. H. Is............	75.5	75.0	71.4	69.7	65.0	63.7	61.0	62.4	65.3	67.6	71.4	73.8	68.6
Port Macquarie District.........	74.0	73.4	71.9	67.3	60.5	56.1	54.3	56.5	60.8	65.9	69.6	72.0	65.3

evident that this area is much more humid and cooler. Clouds very often cover the tops of the mountains and rainfalls are more frequent there than on the low part of the island.

The comparison of the average monthly temperatures shows that the climate of Lord Howe Island is distinctly warmer than in Sydney (5.7°F. in year's temperature) and noticeably warmer than in Port Macquarie. The climate is more moderate, with only 14° of difference between the warmer and colder months, while in Sydney it is 19.9°, and in Port Macquarie 19.7°. This gives good ground for the existence of a number of tropical plants and animals, but it seems that the high humidity is a strong handicap for elements of the flora and fauna which prefer arid conditions.

It is necessary to add that the island is subject at times to strong winds and high seas. It is never very cold, as the warm current, which is also responsible for the most southerly coral reef in the world, helps to maintain an even climate which rarely goes below 60 or above 80 degrees Fahrenheit.

Annual rainfall is about 75 inches.

If we take meteorological data over the period from 1917 to 1938, the average annual rainfall was 67.30 inches. The mean daily temperature over the same period was 66.4 degrees, the mean daily maximum being 71.9 degrees and the mean daily minimum 60.9 degrees, with a difference only in 11 degrees. The highest reading recorded during that period was 89.0 degrees and the lowest 42.8 degrees.

Oliver (1917) gives the following tables on the climate of Lord Howe Island.

Atmospheric pressure varies regularly with the direction of the wind, being highest in south-east and east weather, and lowest in north-west and west weather. The highest reading recorded was 774.4 mm., on 9 June, 1912, east wind; the lowest, 750.3 mm., on 16 September, 1911, wind north-west.

Temperature, judged by both season and direction of wind, varies in a regular manner. The maximum temperature recorded was 30° C., on 8 February, 1912; the minimum, 6.1° C., on 30 August, 1911.

Rainfall is distributed fairly evenly throughout the year, though the average for the winter months is higher than that of the summer months. The average annual rainfall for 12 years is 1,818 mm., on 196 days. During the period selected for analysis, out of a total of 1,265 mm., 779 mm., or over 60 per cent, fell during northerly weather.

SOILS

The island consists practically of but two geological formations: a basaltic series forming about two-thirds of the island, and a thin-bedded calcareous deposit composed of coral sand, covering the lower ground and flanking the three isolated volcanic masses.

This coral-sand rock consists of comminuted and completely rounded coral debris, with grains of volcanic material such as augite, magnatite, and altered lava, with occasional fragments of echinoderms, shells, foraminifera, and other invertebrates. Generally speaking, the constituents of the coral-sand rock agree very closely with the component particles of the present beach at the island. It varies in thickness, and its greatest elevation is about 250 feet above sea level.

In such way the island is composed of two distinct types of rock, the older or base being of volcanic origin, and the upper of decomposed coral formed into a coarse sort of sandstone.

A noticeable feature of the coral rock is the stratification in layers; most of the layers are inclined at an angle of about 30 degrees. This lifting was thought to be caused by earth

FIG. 4. Inhabited area of the island, "The Old Settlement." Large trees are araucarias, introduced from Norfolk Island. In mid-photo are the dominating Howea palms. A line of surf marks the boundary of the coral reef. Rabbit Island in background. Photo by Miss Z. Liepa.

TABLE 2
WEATHER DATA, BY MONTHS, LORD HOWE ISLAND

	BAROMETER	TEMPERATURE (C.°)			RAINFALL		RELATIVE HUMIDITY	CLOUD	WIND
	Mm.	Min.	Max.	Mean	Days	Mm.	Per Cent	0–10	Direction
1911									
July............	762	13.1	17.9	15.5	21	192	79	6.4	S.W., S.E.
August.........	764	12.0	17.4	14.7	22	97	75	5.9	S.E.
September......	762	13.6	20.2	16.9	8	154	75	7.1	S.W.
October........	764	14.4	21.5	17.9	11	132	66	5.7	S.W.
November.....	762	16.8	23.8	20.3	8	91	73	5.6	N.W., S.W.
December......	757	19.2	26.1	22.6	6	17	73	6.4	N.W.
1912									
January........	760	18.8	25.5	22.2	10	83	65	6.2	S.E.
February.......	762	19.2	26.1	22.6	5	83	66	6.2	S.E.
March.........	761	18.3	25.3	21.8	14	73	62	7.0	S.E.
April..........	762	17.2	23.4	20.3	14	102	71	7.5	S.W.
May...........	764	14.1	20.5	17.3	20	113	71	6.4	S.E.
June..........	766	14.4	19.2	16.7	15	128	72	6.3	S.
Averages.......	762	15.9	22.2	19.1	154	1,265	71	6.4	

movements, but the theory now is held that the sand was deposited on the slanting sides of hummocks by the wind and hardened in successive layers when soaked with rain water.

The absence of shells in the coral rock is considered evidence that wind also played a part in carrying the sand into position, as shells, being heavier, were not carried as far as the sand.

There have been several uplifts on the whole island, and in one spot in particular the coral rock is seen about 400 feet above sea level. A portion of the west coast near the boat landing, seems to have sunk in recent times, as tree trunks and roots have been formed in position in the mud or sand, though now covered with 6 ft. or more of water at high tide.

The soil on the lower parts of the island is very rich in places, especially those parts which have been fertilized by decaying banyan trees, etc.

Most of the hill country is too rough and stony for cultivation, and the total area available for cultivation does not amount to more than 2,000 acres (Figs. 3, 4).

Before the advent of man on Lord Howe Island the only animals that had any effect on the plant formations and the soil were two species of burrowing petrels, *Puffinus carneipes* and *Pterodroma melanopus*. In talus slopes near the sea these birds make their burrows each year, completely overturning the soil and replenishing it with a rich manure; but whether or not this process is essential to bringing forth the edaphic conditions which result in the tussock sedge and herbaceous plant formations found there is difficult to say. These birds may have played a part also in the destruction of fossils.

VEGETATION

Oliver (1917) has made an analysis of the flora, and has stated that the whole flora contains 209 species of plants, among which 70, or 33 per cent, are endemic. In this number are not included 30 species of introduced plants and all cultivated plants.

Of the 169 genera of vascular plants 4 genera are endemic (*Colmeroia* and *Hedyscepe* are allied to New Zealand forms, *Negria* to

TABLE 3
THE DURATION AND CHARACTER OF WEATHER AT LORD HOWE ISLAND, CLASSED BY WIND-DIRECTION

	BAROMETER	TEMPERATURE (C.°)			RAINFALL		RELATIVE HUMIDITY	CLOUD	WIND
	Mm.	Min.	Max.	Mean	Days	Mm.	Per Cent	0–10	Days
South-east..........	764	15.3	21.9	18.6	23	44	67	6.0	71
East...............	765	16.2	22.6	19.4	12	75	70	6.6	28
North-east.........	764	15.7	22.5	19.1	17	136	71	5.8	39
North.............	761	18.0	23.2	20.6	20	317	77	8.2	30
North-west.........	760	18.6	24.2	21.4	21	326	77	7.4	46
West.............	760	14.3	22.5	18.4	13	165	77	7.3	22
South-west.........	761	15.0	21.8	18.4	34	157	69	5.7	80
South.............	762	15.2	21.7	18.5	14	45	70	5.7	50

both New Zealand and New Caledonian genera, while *Howea* is related to Malayan and tropical Australian genera).

Of the non-endemic genera 95 are widely distributed, occurring in Australia, New Zealand, and the rest of Polynesia exclusive of New Zealand; 47 more range widely throughout tropical countries, but do not reach New Zealand. Their presence may be due largely to the accident of latitude, and stamps the flora as subtropical. The remaining genera have the following range: New Zealand 1 (*Carmichaelia*), Australia 5, Polynesia 3, New Zealand and Australia 11, New Zealand and Polynesia 2, Africa 1 (*Moraea*).

Numerically, therefore, Australian genera (158) preponderate; Polynesia (exclusive of New Zealand) comes second with 147, and New Zealand has 109 genera. The presence of a large proportion of widely distributed genera and species might have been expected in the flora of an isolated island, because species possessing facilities for wide dispersal would naturally form the bulk of immigrants after land connection has been severed.

The author thinks that the presence on the island of the wedding lily, *Moraea Robinsoniana* Moore and Muell., is not a case of discontinuous distribution. It is more probable that it was transported by whalers, whose vessels very often landed on Lord Howe Island for fresh water. The whalers as a rule were visiting the cold waters of the southern hemisphere, and could easily transport unwittingly the seeds of this ornamental plant. This suggestion is not only theoretical: J. W. Maiden (1898) wrote: "The industry (of onions) commenced about fifty years ago through the finding on the beach (by Mrs. Andrew) of two or three onions which had been thrown overboard by a passing vessel." During stay in harbour the whalers' vessels usually did some cleaning and repair work, and all rubbish was thrown overboard.

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A Review of Australian Species of *Laphria* (Asilidae, Diptera), with Descriptions of Three New Species from Lord Howe Island

S. J. PARAMONOV[1]

KEY TO THE AUSTRALIAN SPECIES OF *Laphria*

1. Legs quite black, but can be covered partly by yellow hairs; if not very intense, always uniformly coloured 2

   Legs always partly yellow or orange . . 12

2. Wings marked with black and bright yellow or orange (Fig. 1). New South Wales . . . . . **L. ornatipennis** Macquart, ♂, ♀

   Wings hyaline or blackish, never with yellow markings 3

3. Hind margin of scutellum at most with four bristles, the central pair weaker and shorter than the lateral pair (Fig. 2*a*). 1 supraalar and 1 notopleural bristle. One black bristle at sides of tergites 1–5. Western Australia . . . . **L. clavata** White, ♂, ♀

   Hind margin of scutellum with more than 4 bristles (Fig. 2*b*); if there are only 4 bristles, the middle pair is not shorter than the lateral one. Number of supraalar, notopleural and lateral bristles on abdomen not as above . . . . 4[2]

4. Spots at sides of abdomen and hairs on the spots distinctly yellow; the lateral bristles are also yellow. Hairs and bristles very numerous and long. Queensland . . . . **L. reginae**, sp. nov., ♂, ♀

   Spots at sides of abdomen pure white . . 5

5. Hairs on underside of head and on face reddish-yellow. Bristles at sides of abdomen numerous: on 1st tergite 4–5, on 2nd 3, on following 2. Lord Howe Island . . . . **L. zentae**, sp. nov., ♂, ♀

   Hairs on underside of head and on face whitish. Bristles on sides of abdomen not so numerous; usually only one on each tergite 6

6. Wings quite black. Sides of mesonotum not silvery-marked. Disc of scutellum shining. Postscutellum with yellowish, not very noticeable dust 7

   Wings with black colour only along the veins. Disc of scutellum dusted. Postscutellum with strong silvery dust, similar dust on the sides of mesonotum . . 8

7. A very sharply marked cross furrow below the base of antennae (Fig. 4*a*). Proboscis longer than the height of head. Hairs on underside of hind tibiae whitish. Western Australia . . **L. leei**, sp. nov., ♀

   Only a slightly marked cross furrow below the base of antennae or furrow absent

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[1] Division of Entomology, C. S. I. R. O., Canberra, Australia. Manuscript received May 4, 1957.
[2] *L. niveifacies* from Tasmania belongs to this group, but the description by Macquart is too short. Only after a study of all Tasmanian species of *Laphria* will it be possible to determine exactly this species of Macquart.

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(Fig. 4*b*). Proboscis shorter than the height of head. Hairs on underside of hind tibiae black. Queensland, North Australia....**L. maura**, sp. nov., ♂, ♀

8. Abdomen partly yellow. Western Australia......**L. lukinsi**, sp. nov., ♂, ♀

   Abdomen wholly black..............9

9. Prescutellar area (its declining part) covered with short bristles. Only one bristle on each segment of abdomen, at sides. New South Wales, Western Australia...............**L. dayi**, sp. nov., ♂, ♀

   Prescutellar area (its declining part) is quite bare, or the hairs are quite the same as the others on the mesonotum.....**10**

10. Scutellum partly reddish, also the postalar calli. Queensland, Western Australia ....**L. modesta**, sp. nov., ♂, ♀

    Scutellum and postalar calli always black **11**

11. Wings distinctly yellow at base. New South Wales..**L. campbelli**, sp. nov., ♂

    Wings at base not yellow. New South Wales, Victoria..................... ....**L. mauroides**, sp. nov., ♂, ♀

12. Tibiae always partly yellow........**13**

    Tibiae always wholly black........**20**

13. Ground colour of abdomen black, with the usual white or slightly yellowish spots at sides of 2nd–4th tergites....**14**

    Ground colour of abdomen yellow, or with large yellow spots, or with narrow yellow lateral stripe, or at least with the last two tergites yellow **15**

14. Length 12 mm. All femora yellow on their basal halves. White tomentose spots on the first four tergites. Thorax and scutellum dull black. Queensland........... ....**L. fulvipes** Ricardo, ♀

Length 13.5 mm. or more. Anterior and middle femora with only yellow spots on basal halves. White spots only on 2nd, 3rd and 4th tergites. Mesonotum (if the insect is not greasy) with spots of golden dust on humeral calli and behind them, four golden markings at suture: two subcentral and two lateral; golden prescutellar area and golden disc of scutellum. Lord Howe Island.............. ....**L. pacifica**, sp. nov., ♂, ♀

15. Only the last two tergites are yellow or reddish. Abdomen with white spots at sides. Queensland.................... ....**L. bancrofti** Ricardo, ♀

    The yellow or reddish colour occupies a greater area of the abdomen. Abdomen without white spots at sides........**16**

16. Only sides of tergites reddish, forming a narrow lateral stripe at sides of abdomen........................**17**

    More than lateral stripes are reddish or yellow........................**18**

17. Tibiae with extremely long, bright yellow hairs. Fore femora nearly wholly black. "Australia"....**L. hirta** Ricardo, ♂, ♀

    Tibiae with extremely long black hairs. Fore femora with very large yellow spots on underside. Lord Howe Island...... ....**L. howeana**, sp. nov., ♂, ♀

18. Borders of 2nd, 3rd and 4th tergites yellow. Length 11 mm. "Australia"....... ....**L. calopogon** Bigot, ♂

    Greater part of abdomen golden-yellow, the middle part can be camouflaged with black hairs. Length 12–13 mm.......**19**

19. Anterior and middle femora black. Queensland..**L. burnsi**, sp. nov., ♂, ♀

    Anterior and middle femora at base yellow (Fig. 6*a*). New South Wales, Queensland............**L. variana** White, ♂

20. Femora yellow. Abdomen without white lateral spots. Tasmania...............
......**L. flavifemorata** Macquart, ♀

Femora predominantly black, partly yellow. Abdomen with lateral white spots
............................**21**

21. Legs black, only two-thirds of posterior femora yellow. Western Australia, Tasmania, New South Wales.............
............**L. telecles** Walker, ♂, ♀

More parts of legs than two-thirds of hind femora are yellow.............**22**

22. Anterior legs wholly black. Apical part of female abdomen depressed laterally (Fig. 3*a*). New South Wales, Victoria..
.............**L. comata** White, ♂, ♀

Anterior femora at base at least with a yellow spot (Fig. 6*b*). Apical part of female abdomen rounded, not laterally depressed (Fig. 3*b*). Nearly whole of Australia..**L. rufifemorata** Macquart, ♂, ♀

Laphria zentae sp. nov., ♂, ♀

Belongs to the group with completely black legs.

Ground colour of body shining black. Head covered with a whitish dust, hairs and semi-bristles of face reddish-yellow; the central part of face (moustache) with black bristles. Some black bristles below base of antennae, on ocellar tubercle and on occiput, especially on the excavation of vertex. Hairs on antennae black. Third antennal joint elongated, elliptical. Proboscis short, only about half as long as the vertical diameter of head.

Sides of thorax, postscutellum and coxae with white dust. Mesonotum with reddish-yellow markings on humeral calli, two transversal spots of the same colour behind them, with a silvery marking at each side of suture, and similar marking near postalar calli. Scutellum with numerous black marginal bristles

and with short yellowish and black hairs on the disc (Fig. 2*b*). In notopleural area (hind part) 3–4 long black bristles, 3–4 similar bristles in supraalar area, and 3–4 more on postalar calli. Prescutellar area nude.

Wings blackish in apical half and along hind margin, basal half nearly hyaline. Vein closing the discal cell (tp) straight. Cross vein r–m at end of basal third of the discal cell. First posterior cell at apex broad, slightly narrowed. Halteres yellowish.

Legs black, long and slender, hind femora only slightly swollen. Underside of anterior tibiae and metatarsi with very short but dense yellow hairs, in the form of brushes; lateral and dorsal sides with very long, black hairs and bristles; anterior femora with yellow and black hairs, the black ones only on upperside, but without strong bristles. Mid-legs very similar to the anterior, but without the yellow brushes and with some strong bristles on apical part of femora. Hind legs similar to the middle ones, metatarsi not swollen, maximally as broad as apex of tibiae and nearly as long as three following segments combined. Claws of all legs slightly yellow at base. Pulvilli yellowish.

Abdomen elongated, longer than in other species, black, shining, laterally with white spots on first to fourth tergites. Hairs on lateral side yellowish, not dense. At sides of first tergite 4 black bristles, on the second 2–3, on third, fourth and fifth 2 bristles. Genitalia rather large, black, shining, with black and whitish hairs.

Female differs only slightly from the male. Long yellowish hairs are paler, whitish, but on head reddish as in male; abdomen slightly broader.

Length of body 19 mm., of wing 15 mm.

1 ♂, 29.xi.1955 (type), 1 ♂, 5.xii.1955, Lord Howe Island, N. S. Wales (S. J. Paramonov and Z. Liepa); 1 ♂, 19.ii.1957, North Bay, Lord Howe Island (Z. Liepa); 1 ♀, 29.xi.1955, 1 ♀, 28.xi.1955, Lord Howe Island (S. J. Paramonov and Z. Liepa).

Type in the Division of Entomology Museum, C.S.I.R.O., Canberra.

This species is not very closely related to the mainland species, but superficially looks very similar to *L. dayi* sp. nov.

Laphria pacifica sp. nov., ♂, ♀

From the group with yellow-marked tibiae.

Face and frons dusted with yellow; face with long, black bristles of moustache and below the antennae, and with central part covered with dense golden scalelike hairs. Underside of head with white hairs. Most of occiput, ocellar tubercle and antennae clothed with black hairs. Third antennal segment extremely elongated, narrow, broadening slightly towards the apex. Proboscis long, about as long as vertical diameter of head.

Mesonotum with golden markings on humeral calli; behind them on the sides of sutura, two small subcentral markings; golden markings also on prescutellar area and on the disc of scutellum. Propleurae and mesopleurae also golden but not so distinct as the mesonotum. Sides of thorax whitish and yellow dusted. Two notopleural bristles, 3–4 supra-alar, 4 postalar. Prescutellar area quite nude. Scutellum with numerous long, black and white, marginal hair-bristles; disc with very short, yellowish ones.

Wings on apical two-thirds black, basal third hyaline. Veins closing the fourth posterior cell not straight but convex. Halteres yellow.

Legs black, but all femora and tibiae with reddish-yellow markings. All femora very swollen, the anterior only slightly yellow at base; the middle with basal third yellow; the hind with basal half yellow. Hairs on yellow parts of legs yellow, on remainder black. Bristles on femora practically absent. Tibiae with extremely long hair-bristles, especially the middle tibiae, and with yellow markings occupying their middle half. Hind tibiae distinctly curved. Pulvilli yellow.

Abdomen black, with slight blue sheen, and with 3 small white or slightly yellowish spots of dust on sides of second, third and fourth tergites. Hairs on sides yellowish, not very numerous. Genitalia very large, swollen.

Female very similar to the male. The abdomen comparatively broader, and the spots at sides of second to fourth tergites larger and whiter. Hind metatarsus distinctly swollen.

Length of body 14.4 mm., of wing 11 mm.

1 ♂, 18.xii.1955 (type), Lord Howe Island, N. S. Wales (S. J. Paramonov); 1 ♂, 1 ♀, 28.xi.1955, 1 ♀, 30.xi.1955, Lord Howe Island (S. J. Paramonov and Z. Liepa).

Type in the Division of Entomology Museum, C.S.I.R.O., Canberra.

Laphria howeana sp. nov., ♂, ♀

Belongs to the group with yellow-marked tibiae, but without spots of white or yellow dust at sides of abdomen.

Very similar to *L. pacifica* sp. nov., but white spots at sides of abdomen replaced by a narrow reddish longitudinal stripe. This stripe is not visible from above but is clearly visible from the lateral view. Golden markings on mesonotum brighter, postscutellum silvery. The yellow colour on legs is brighter and more extensive: it occupies the basal half of anterior and middle femora and a slightly greater area of hind femora.

Length of body 18 mm., of wing 14 mm.

1 ♂, 29.xi.1955 (type), 7 ♂♂, 25.xi.–29.xi.1955, 11 ♀♀, 23.xi.–29.xi.1955, Lord Howe Island, N. S. Wales (S. J. Paramonov and Z. Liepa); 3 ♀♀, 20.xi.1956, Dawson Range, Lord Howe Island (Z. Liepa).

Type in the Division of Entomology Museum, C.S.I.R.O., Canberra.

Some specimens have nearly hyaline wings, although as a rule the apical two-thirds is dark.

It is quite evident that all three described species are common on the island, but other representatives of Asilidae are very rare. Only one species of Dasypogoninae was collected, but no Asilinae, Stichopogoninae or Lepto-

gastrinae were seen on the island by myself or by my assistant.

All three described species are rather closely related to the mainland species, but none of the mainland species were found on the island. The circumstance that all three species of the same genus are different from the mainland species seems to be a convincing sign of true paleoendemism.

The relationship between species from Lord Howe Island and those from the mainland are easily seen from the above given key to identification of all Australian species known to the author.

Laphria clavata White, ♂, ♀

Laphria clavata White, 1913. Roy. Soc. Tasmania, Proc. 1913: 273.

Laphria clavata Hardy, 1929. Linn. Soc. N. S. Wales, Proc. 54: 357.

Laphria clavata Hardy, 1934. Ann. and Mag. Nat. Hist. (10) 13: 519.

Type in the British Museum, London.

This species is recorded only from Western Australia. On the abdomen the small white lateral spots are present only on the 2nd, 3rd and 4th tergites, but not on the 1st. Claws and pulvilli in female about as long as in male. Wings distinctly smoky in their distal half. A rather common species (Fig. 2a).

Laphria ornatipennis Macquart, ♂, ♀

Laphria ornatipennis Macquart, 1849. Dipt. Exot., Sup. 4: 73.

Laphria ornatipennis Ricardo, 1913. Ann. and Mag. Nat. Hist. (8) 11: 156.

Laphria ornatipennis Hardy, 1929. Linn. Soc. N. S. Wales, Proc. 54: 357.

Laphria ornatipennis Hardy, 1934. Ann. and Mag. Nat. Hist. (10) 13: 520.

Type in the Paris Museum.

The moustache in the male consists of soft, long golden hairs and bristles, in the female of stout black bristles and some yellow hairs. A bright yellow third antennal joint is char-

acteristic of this species alone. Two bright yellow triangles in the fore part of the wing also separate this species at once from all other species (Fig. 1).

Distributed in Eastern states of Australia and not very common.

The author has seen specimens from the following localities: New South Wales: 1 ♂, 31.xii.1923, Broken Bay (Mackerras); 1 ♂, 1.i.1926, National Park (Mackerras); 1 ♂, 12.iii.1953, Colo Vale (R. Mykytowycz); 1 ♀, 12.i.1935, 1 ♀, 25.ii. 1935, Killara (M. F. Day); 1 ♀, 17.i. 1935, Port Macquarie (M. F. Day); 1 ♀, 2.xii. 1950, Nellingen (K. L. H. Key).
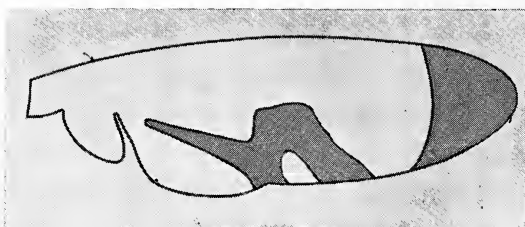
FIG. 1. Pattern of wing of Laphria ornatipennis Macq. (Shaded portion is brown, unshaded portion is yellow.)

Laphria fulvipes Ricardo, ♀

Laphria fulvipes Ricardo, 1913. Ann. and Mag. Nat. Hist. (8) 11: 158.

Laphria fulvipes Hardy, 1929. Linn. Soc. N. S. Wales, Proc. 54: 359.

Laphria fulvipes Hardy, 1934. Ann. and Mag. Nat. Hist. (10) 13: 522.

Type in the British Museum, London.

Only the female is described. This species is unknown to the author.

FIG. 2. a, Scutellum of Laphria clavata White. b, Scutellum of Laphria zentae sp. nov.

Laphria bancrofti Ricardo, ♂, ♀

Laphria bancrofti Ricardo, 1913. Ann. and
   Mag. Nat. Hist. (8) 11: 158.
Laphria bancrofti Hardy, 1929. Linn. Soc. N.
   S. Wales, Proc. 54: 359.
Laphria bancrofti Hardy, 1934. Ann. and Mag.
   Nat. Hist. (10) 13: 522.
   Type (female) in the British Museum.
   The considerable difference in the size of
the sexes (♀ —11 mm., ♂ —17 mm.), the
absence of spots on the sides of the male
abdomen, and the difference in the colour of
the femora show that the male probably does
not belong to the same species as the female.
   The author has seen only 2 specimens: 1
♀, Palm Island, Queensland (Bancroft) and
1 ♀, 25.i.1949, Goodna, Queensland (I. F.
B. Common), but he is not quite sure that
the identification of the species is correct,
both specimens have pure white, rather than
yellow, markings on the mesonotum.

Laphria hirta Ricardo, ♂, ♀

Laphria hirta Ricardo, 1913. Ann. and Mag.
   Nat. Hist. (8) 11: 159.
Laphria hirta Hardy, 1929. Linn. Soc. N. S.
   Wales, Proc. 54: 359.
Laphria hirta Hardy, 1934. Ann. and Mag.
   Nat. Hist. (10) 13: 522.
   Type (male) in the British Museum.
   The author has seen only one male speci-
men—1 ♂, 30.x.1950, Heathcote, New South
Wales (T. R. Henry). This species is easily
recognisable by the yellow spots laterally on
each tergite, except the basal one. Hairs of
face orange; on the frons and upper part of
occiput black, on the lower part of occiput
pure white. Moustache consists of about 12
long, fine, black bristles. Proboscis long, as
long as the head is high, compressed laterally.
All femora extremely swollen; all tibiae with
extremely dense and long hairs, each of which
is about three times as long as the diameter
of the corresponding tibia. Hypopygium large,
black, shining, rounded, as long as the last
tergite. Sides of tergites with long, dense,

orange hairs, directed downwards.
   Female (hitherto unrecorded). 1 ♀, 14.xi.
1926, Woodford, New South Wales (Mac-
kerras) is very similar to the male, but the
hairs on the face are predominantly white,
only slightly yellow at the sides, and all the
femora swollen, though not to the same ex-
tent as in male.

Laphria telecles Walker, ♂, ♀

Laphria telecles Walker, 1849. List Dipt. Brit.
   Mus. 2: 376.
Laphria telecles Walker, 1855. List Dipt. Brit.
   Mus. 7, Sup. 3: 559.
Laphria telecles Ricardo, 1913. Ann. and Mag.
   Nat. Hist. (8) 11: 154.
Laphria telecles White, 1916. Roy. Soc. Tas-
   mania, Proc. 1916: 165.
Laphria telecles Hardy, 1929. Linn. Soc. N. S.
   Wales, Proc. 54: 358.
   Types in the British Museum; from West-
ern Australia.
   The author has seen specimens from the
following localities: 1 ♂, 5.xii.1936, Pember-
ton, Western Australia (K. R. Norris); 1 ♂,
25.xi.1914, Urella, New South Wales; 1 ♀,
13.ii.1948, Bendora, near Canberra, Australian
Capital Territory (Paramonov); 1 ♀, 6.ii.
1923, Strahan, Tasmania (A. Tonnoir); 1 ♀,
30.i.1948, 13 mls. N. W. of Broadmarsh,
Tasmania (Key, Carne and Kerr).

Laphria variana White, ♂, ♀

Laphria variana White, 1917. Roy. Soc. Tas-
   mania, Proc. 1917: 72.
Laphria variana Hardy, 1929. Linn. Soc. N.
   S. Wales, Proc. 54: 358.
Laphria variana Hardy, 1934. Ann. and Mag.
   Nat. Hist. (10) 13: 520.
   Type (male) in the British Museum.
   The remark of G. H. Hardy, ". . . the allo-
type female and a paratype are in Mr. J.
Mann's collection," is based on a misunder-
standing of the term "paratype." White de-
scribed a "holotype" (single specimen) and
it is quite evident that no paratypes existed. It

is also a very questionable practice to call a specimen of the second sex "allotype," without publishing an appropriate description.

The author has examined 1 ♂, 1924, Eidsvold, Queensland (Bancroft), and females from the following localities in Queensland: 2 ♀ ♀, Eidsvold; 1 ♀, 4.iv.1924, 1 ♀, ii.1923, Eidsvold; 1 ♀, 7.xi.1926, Lake Barrine (Goldfinch); 1 ♀, 1916, Tambourine; 1 ♀, x.–iv.1930, Eidsvold (T. L. Bancroft).

The female (hitherto unrecorded) is very similar to the male, but the central stripe of the abdomen is really black (in the male very often the black hairs only camouflage the yellow-red colour of the abdomen).

Both sexes of this species have anterior femora of a very peculiar colour pattern: on the underside and on the sides they are yellow, excepting for a small black apical area, but the upperside is black (Fig. 6a); in other species the dividing line of the areas of black and yellow colour is transverse to the long axis of the femur.

Laphria comata White, ♂, ♀

Laphria comata White, 1917. Roy. Soc. Tasmania, Proc. 1917: 85.

Laphria comata Hardy, 1929. Linn. Soc. N. S. Wales, Proc. 54: 358.

Laphria comata Hardy, 1934. Ann. and Mag. Nat. Hist. (10) 13: 521.

Type (male) in the British Museum.

The female was unknown up to the present; the note of G. H. Hardy, "the allotype female is in my own collection" cannot be accepted because this author has not published the description of the female.

The female is very similar to the male, but all femora are less strongly incrassate. From the females of other species it differs in having a very acute ovipositor, which, together with some of the apical abdominal segments, is strongly compressed laterally (Fig. 3a). This refutes the opinion of G. H. Hardy, 1934, that this form is only colour variety of *L. rufifemorata* Macq.
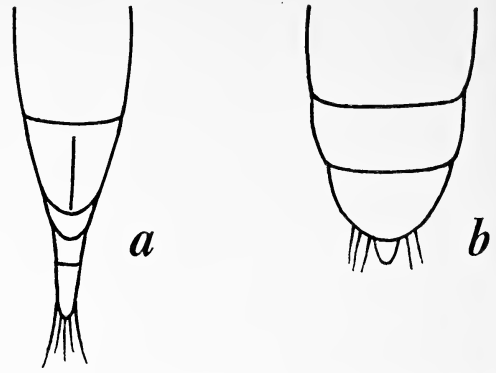
FIG. 3. *a*, Apical part of *Laphria comata* White, female. *b*, Apical part of *Laphria rufifemorata* Macq., female.

The author has examined the following specimens: Australian Capital Territory: 2 ♂ ♂, 17.ii.1953, Bendora, near Canberra (S. J. Paramonov); 7 ♀ ♀, 6.ii.1952, Lee's Springs, near Canberra (S. J. Paramonov); 1 ♀, 13.ii.1952, Mt. Gingera (S. J. Paramonov); 1 ♀, 15.iii.1948, 1 ♀, 31.iii.1948, Blundell's, near Canberra (S. J. Paramonov); 1 ♀, iii.1951, Westridge, Canberra (R. Richmond); 1 ♀, 15.iv.1953, Bendora (S. J. Paramonov); 1 ♀, 21.i.1931, Coree Creek, near Canberra (L. F. Graham). New South Wales: 1 ♂, 16.iv.1949, Chatswood (A. Dyce); 1 ♂, 11.i.1956, 7 ♀ ♀, 7.i.1956, Tubrabucca Ck., Barrington Tops, 4200 ft. (I. F. B. Common); 1 ♀, 9.iv.1949, Barrington Tops (S. J. Paramonov); 1 ♀, 28.ii.1936, Mt. Victoria (M. F. Day); 1 ♀, 25.xi.1914, Urella.

Laphria flavifemorata Macquart, ♀

Laphria flavifemorata Macquart, 1849. Dipt. Exot., Sup. 4: 73.

Laphria flavifemorata Ricardo, 1913. Ann. and Mag. Nat. Hist. (8) 11: 157.

Laphria flavifemorata Hardy, 1929. Linn. Soc. N. S. Wales, Proc. 54: 358.

Laphria flavifemorata Hardy, 1934. Ann. and Mag. Nat. Hist. (10) 13: 521.

Type in the Paris Museum; from Tasmania.

This species is unknown to the author. There are no grounds for the remark of G.

H. Hardy, 1934, that "the type-locality of this species was probably Sydney, not Tasmania as recorded." G. H. Hardy, in various papers, expressed doubts about the validity of Macquart's recording many species as from Tasmania, as he had not found them there himself. However, in most cases I have examined, Macquart's data were quite correct.

In his paper G. H. Hardy (1929) also writes: "The leg coloration is variable, having a complete range as is found in the three forms mentioned above (*L. rufifemorata* Macq., *L. telecles* Walk., *L. comata* White), but is to be distinguished from them by the slender femora which conform to those species placed in group I (*L. tectamus* Walk., *L. clavatus* White, *L. ornatipennis* Macq.)."

G. H. Hardy, 1929, did not give the description of the male, nor the date and locality of collection of the specimens examined, and his expression, "the leg coloration is variable, having a complete range" is very obscure. It is probable that he was dealing with a mixture of species as he had also done with *Comptosia*, *Oncodes*, and other genera, when at least half a dozen species were confused together.

This species can be recognised easily by its yellow femora, concolorous abdomen devoid of lateral white spots, nonincrassate femora, and its venation.

Laphria rufifemorata Macquart, ♂, ♀

Laphria rufifemorata Macquart, 1844. Dipt. Exot., Sup. 1: 73.
Laphria rufifemorata Walker, 1855. List Dipt. Brit. Mus., Sup. 3: 559.
Laphria rufifemorata Ricardo, 1913. Ann. and Mag. Nat. Hist. (8) 11: 154.
Laphria rufifemorata White, 1916. Roy. Soc. Tasmania, Proc. 1916: 166.
Laphria rufifemorata Hardy, 1929. Linn. Soc. N. S. Wales, Proc. 54: 257.
Laphria rufifemorata Hardy, 1934. Ann. and Mag. Nat. Hist. (10) 13: 520.

One of the commonest species in Australia, possibly distributed throughout the whole continent (Figs. 3*b*, 6*b*).

Type in the Paris Museum.

The author has examined specimens from the following localities: Australian Capital Territory: 3 ♂♂, 1 ♀, 15.iv.1953, Bendora (S. J. Paramonov); 1 ♂, 1 ♀, 28.iii.1951, Mt. Gingera (Common & Day); 1 ♂, 4 ♀♀, 6.iii.1952, Mt. Gingera (S. J. Paramonov); 1 ♂, 6.iii.1952, Mt. Gingera (H. M. Cane); 1 ♂, 23.i.1952, Lee's Springs (I. F. B. Common); 1 ♀, 15.iii.1950, Lee's Springs (S. J. Paramonov); 1 ♀, 14.i.1950, 1 ♀, 31.i.1952, Mt. Gingera (S. J. Paramonov); 1 ♀, 14.ii.1953, Mt. Gingera (I. F. B. Common); 2 ♀♀, 2.iii.1949, 1 ♀, 31.i.1952, Bendora (S. J. Paramonov); 1 ♀, iii.1948, Brindabella; 1 ♀, 10.iv.1951, Brindabella (Small). New South Wales: 1 ♂, 12.xi.1953, Durras (S. J. Paramonov); 2 ♂♂, 8.i.1956, Upper Manning Riv., Barrington Tops, 4500 ft. (I. F. B. Common); 1 ♀, vii.1949, Kincumber; 1 ♀, 14.x.1952, 4 mls. N. of Bateman's Bay (S. J. Paramonov); 1 ♀, 12.xii.1951, 40 mls. N. of Sydney (E. F. Riek); 1 ♀, 22.xi.1925, Gordon (Harrison); 1 ♀, Acacia Plat. (J. Armstrong) Victoria: 1 ♀, 23.ii.1951, Mitta Mitta (B. Given). Tasmania: 2 ♂♂, 25.xii.1922, 1 ♀, 31.xii.1922, Advent Bay (A. Tonnoir); 2 ♀♀, 30.i.1949, Erriba (E. F. Riek); 1 ♀, 10.i.1932, Mt. Wellington, Ferntree (L. F. Graham); 1 ♀, 26.i.1948, near Wadamana (Key, Carne, and Kerr); 1 ♀, 11.ii.1949, Rose's Tier (R. A. Free).

Laphria calopogon Bigot, ♂

Laphria calopogon Bigot, 1876 (1878). Soc. Ent. de France, Ann. (5): 226.
Laphria calopogon Ricardo, 1913. Ann. and Mag. Nat. Hist. (8) 11: 157.
Laphria calopogon Hardy, 1929. Linn. Soc. N. S. Wales, Proc. 54: 358.
Laphria calopogon Hardy, 1934. Ann. and Mag. Nat. Hist. (10) 13: 521.

Type presumably in the British Museum, London.

Since Bigot's time this species has not been recognised. Length of body 11 mm. Locality: "Australia." Type probably in Bigot's collection.

From the Latin and French descriptions we can extract the following characters: Black, sparsely greyish haired, some long hairs on the underside of abdomen and on the femora and tibiae; sides of face with golden hairs; beard white. Wings broadly black, almost hyaline at base. Halteres pale. Femora and tibiae at base narrowly yellow (or only the posterior tibiae have the yellow basal spots). Apical part of tibiae and underside of tarsi with golden-reddish pubescence. Pulvilli yellow. Margin of 2nd–4th tergite yellow.

Without examination of the type it is difficult to identify this species; close relationship to *L. variana* White is evident.

Laphria niveifacies Macquart

Laphria niveifacies Macquart, 1849. Dipt. Exot., Sup. 4: 73.

Laphria niveifacies Ricardo, 1913. Ann. and Mag. Nat. Hist. (8) 11: 156.

Laphria niveifacies White, 1916. Roy. Soc. Tasmania, Proc. 1916: 167.

Laphria niveifacies Hardy, 1917. Roy. Soc. Tasmania, Proc. 1917: 66.

Laphria niveifacies Hardy, 1929. Linn. Soc. N. S. Wales, Proc. 54: 358.

Laphria niveifacies Hardy, 1934. Ann. and Mag. Nat. Hist. (10) 13: 521.

The type is apparently lost, as it could not be found in the Paris Museum.

Macquart's specimen was stated to be from Tasmania, but the species has not since been found there. Hardy, 1934, doubted the correctness of the locality record and supposed that the specimen came from Sydney, but my own experience has shown that Macquart's data about Tasmanian species were correct; Hardy's failure to find some species in Tasmania is not evidence that they are absent from Tasmania.

This species seems to be very closely related to *L. mauroides* sp. nov.

Laphria leei sp. nov., ♀

Belongs to the group of species with wholly black legs and wings, closely related to *L. maura* sp. nov.

Body black with a slightly bluish sheen, the usual greyish dust on head and underside of thorax almost completely lacking. Below bases of antennae, two-thirds up the height of the face there is a very distinct cross furrow, sharply separating the upper third (Fig. 4*a*). Sides of face with a narrow stripe of whitish hairs, bristles on the disc of the face (moustache) are long, black, but not very numerous.
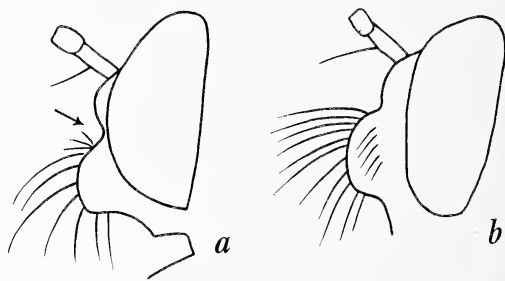
FIG. 4. *a*, Head of *Laphria leei* sp. nov. *b*, Head of *Laphria maura* sp. nov.

Proboscis long, black, shining, compressed laterally, slightly longer than height of head. Hairs on occiput whitish, except for some black ones above, which, however, are comparatively short and not as numerous as in other species.

Mesonotum dull, without grey markings, scutellum shining, with a row of sparse, comparatively weak, shortish marginal bristles. Disc of mesonotum without bristles. Pleurae dull, with some short whitish hairs. On the tubercle in front of halteres is a bunch of numerous, long, black bristles. Halteres yellow. Wings black, only alula and a part of axillar cell are nearly transparent. Fourth posterior cell with the closing vein, slightly convex and forming a very acute angle with m_2. Legs black, shining, with bluish or violet reflection. Pulvilli yellowish. Hairs very short, mostly whitish; bristles comparatively weak, short and not as numerous as in other species.

Hind femora swollen in apical half, but not long.

Abdomen comparatively short, shining, nearly bare; at sides of 2nd–4th tergites weakly developed whitish spots. Genital (last) segment very short. Lateral bristles only on 1st and 2nd tergites, but very weakly developed.

Length of body 16 mm., of wing 12 mm. 1 ♀, 17.i.1951, Wyndham, Kimberley Research Station, Western Australia (L. C. Lee).

Type in the Division of Entomology Museum, C.S.I.R.O., Canberra.

Laphria maura sp. nov., ♂, ♀

Belongs to the group of species with completely black legs and black wings, superficially similar to *L. leei*, but distinguishable easily by the absence of the cross furrow on the face below the antennae (Fig. 4b); by the shorter proboscis, which is shorter than the height of the head; by the presence of silvery spots on the mesonotum and other characters.

Ground colour of body black, shining. Face and occiput white dusted. Face at sides broadly covered by faintly yellowish hairs. Moustache consists of numerous, strong, black bristles. Hairs on underside of head slightly yellowish. Proboscis short, depressed from above. Frons whitish dusted, with light coloured short hairs and two very long black bristles on the ocellar tubercle. Antennae black, the third joint rather long, clavate.

Mesonotum with silvery or golden spots beside humeral calli and another pair of them slightly behind the calli; postalar calli usually golden or yellow dusted. Upper part of mesopleurae with a spot of silvery dust. Pleurae mostly without dust, with black hairs and a tuft of black bristles in front of the halteres which have a yellow knob. Wings rather uniformly black, comparatively broad and short. First posterior cell closed with a slightly concave vein far from the margin of wing.

Legs black, black haired and bristled, but the tibiae have an admixture of whitish hairs. Pulvilli yellow. Hind tibiae short, swollen.

Abdomen black, shining, with lateral whitish spots on tergites 2–4, nearly bare; only on the terminal segments are there more black hairs. Hypopygium of male swollen, but not very large; in female the last segment is short. On tergites 1–6 there are black bristles laterally.

Length of body 11–15 mm., of wing 9–11 mm. Queensland: 1 ♂, xii.1922, Eidsvold (type) and a female; 1 ♂, 19.i.1949, Yeppon (I. F. B. Common); 2 ♂ ♂, 1 ♀, 2.–3.iv.1929, Burnside (T. G. Campbell). The last 3 specimens with a closed first posterior cell.

Type in the Division of Entomology Museum, C.S.I.R.O., Canberra.

Laphria reginae sp. nov., ♂, ♀

Belongs to the group of species with black legs; easily distinguishable by the presence of yellow spots on the abdomen.

Ground colour of body black, slightly shining; legs (in old specimens) may be brown, but never bright yellow or reddish.

Face and underside of thorax with very dense grey dust. Bristles and hairs on the head black, except below, where they are whitish. Bristles and hairs on mesonotum black, but on underside of thorax in the area above the fore coxae the hairs are whitish, and the very long bristles on the tubercle in front of the halteres are reddish. Hairs on mesopleurae long and black. The hairs and bristles on mesonotum are very long and thin. On the anterior part of the mesonotum there are two lateral spots of golden dust (chiefly on the humeral calli and a little behind them). Wings slightly greyish. First posterior cell slightly narrowed at apex. Fourth posterior cell closed, much shorter than discal cell, its apical cross vein convex outwards, forming a very broad angle with m_3. Halteres yellow. In two specimens the second submarginal cell is divided by a supernumerous vein. The possibility is not excluded that these specimens might belong to a distinct species. Legs with very long hairs and bristles, mostly black.

Abdomen with rather bright yellow hairs. The lateral bristles on the first tergite are yellow, the long, strong bristles on the penultimate segment are black. On the sides of the 2nd–6th tergites there are small yellow, almost golden spots. Last genital segment is very short, directed downwards.

Length of body 12 mm., of wing 9 mm.

1 ♂ (type) Tambourine, Queensland, 1916 (Froggatt?); genitalia large, swollen, black, shining; two long lateral forceps on underside, and two very long lateral brushes of black, strong bristles. 1 ♀, Tambourine, Qld. (Davidson?); 1 ♀, 3.xi.1911, Mt. Tambourine, Qld.; 1 ♀, 1917, Mt. Tambourine, Qld.; 1 ♀, 1916, Tambourine, Qld., 1 ♀, 1926, Bulga, New South Wales (Froggatt); (the last two specimens with 3 submarginal cells).

Type (male) in the Division of Entomology Museum, C.S.I.R.O., Canberra.

Laphria mauroides sp. nov., ♂, ♀

Belongs to the group of species with black legs and wings darkened along the veins, closely related to *L. dayi* sp. nov., but distinguishable by the presence, immediately over the scutellum, of short rather strong bristles, even on the declining part of mesonotum, by an irregular disposition of hairs on mesonotum (in *L. dayi* they are less numerous and distributed in longitudinal rows), and moustache tubercle not very sharply separated from the upper part of face.

Body black, shining. Head with greyish dust, very similar to that of *L. dayi* or *L. modesta*.

Mesonotum with similar markings as in *L. dayi*, but with short black hairs irregularly distributed. Wings dark, rather broad, the veins closing the discal and 4th posterior cells very close together and nearly parallel (Fig. 5a). Pleurae nearly entirely grey dusted, only the disc of the mesopleurae black, shining. Legs black, with hairs predominantly white. Femora moderately swollen. Halteres yellow.

Abdomen as in *L. dayi* sp. nov.

Length of body 15 mm., of wing 12.5 mm.

Australian Capital Territory: 1 ♂, 5.ii.1952, Lee's Springs (S. J. Paramonov), (type); 1 ♀, 2.ii.1954, Canberra (S. J. Paramonov); 1 ♀, 6.iv.1948, Blundell's (S. J. Paramonov). New South Wales: 1 ♀, 18.ii.1934, Killara (M. F. Day); 1 ♀, 10.ii.1955, near Queanbeyan (Z. Liepa). Victoria: 1 ♀, 10.ii.1954, Romsey (E. F. Riek).

Type (male) in the Division of Entomology Museum, C.S.I.R.O., Canberra.

Laphria lukinsi sp. nov., ♂, ♀

Belongs to the group of species with black legs. Distinguishable at once by the yellow apical part of the abdomen.

Head black, with yellowish dust, hairs and bristles. The hairs at sides of face are flat and scalelike. Proboscis long, slightly shorter than head height, strongly compressed laterally. Palpi very small, hairs light coloured.

Mesonotum black, dull, with some yellow markings beside humeral calli. Short hairs black, but the longer ones in the prescutellar area yellowish. Bristles black, but those on postalar calli and scutellum yellow, very thin. Disc of scutellum with yellow depressed hairs. Underside of thorax yellowish dusted, with yellowish hairs and bristles. Only one black bristle on mesopleurae. Halteres yellow.
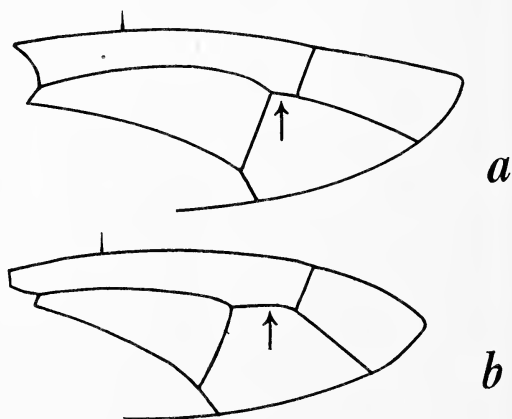
Fig. 5. *a*, Subdiscal cell of *Laphria mauroides* sp. nov. *b*, Subdiscal cell of *Laphria modesta* sp. nov.

Wings in apical two thirds strongly smoked but not black. First posterior cell at apex distinctly narrowed; 4th posterior cell closed close to hind margin of wing, only slightly shorter than discal cell. All veins black.

Legs black, pulvilli yellow, underside of fore tibiae so densely covered with short yellow hairs as to appear yellow. Hairs on tibiae extremely long, thin and yellow. All femora short and very swollen.

Abdomen narrow, cylindrical. First segment black, other segments becoming more reddish towards the apex. Lateral bristles yellow, weak. Discs of tergites with very short black hairs, along the hind margins there are numerous yellow hairs almost forming crossbands. Hypopygium large, very swollen, reddish, with some separate bristles, but lacking tufts.

Length of body 14 mm., of wing 11 mm.

1 ♂, 5.xii.1953 (type), and 1 ♀, 11.xii. 1953, Wyndham, Kimberley Research Station, Western Australia (R. Lukins).

Type (male) in the Division of Entomology Museum, C.S.I.R.O., Canberra.

Laphria modesta sp. nov., ♂, ♀

Belongs to the group of species with black legs and wings with saturated colour along the veins. Closely related to L. mauroides sp. nov., but easily distinguishable by its partly reddish scutellum and by the short subdiscal cell (Fig. 5b), which in L. mauroides is very slightly shorter than the discal cell.

Black, shining. Head with grey dust. Moustache tubercle sharply protuberant in profile (in L. mauroides not strongly separated from the upper part of face). Moustache consists of black bristles, hairs of face whitish. Proboscis short, depressed from above. Third antennal joint elliptical, elongated. Occiput with grey dust and whitish hairs, ocellar tubercle with 2 very strong, long, black bristles. There are some whitish spots on mesonotum beside the humeral calli, but they are poorly developed. Hairs on mesonotum predomi-

nantly whitish. Prescutellar area (declining part) with fine black and white hairs. Disc of scutellum and postalar calli reddish. Marginal bristles of scutellum very thin, hair-like, whitish; postnotum with strong white dust. Bunch of long hairs in front of halteres black. Halteres yellow. Wings rather strongly smoked, more so along the veins. First posterior cell distinctly narrowed at apex. Fourth posterior cell distinctly shorter than discal cell; the veins closing the discal and 4th posterior cell are not parallel; the lower angle of the latter is acute.

Legs black, mostly with white, shortish hairs; the fore tibiae lacking the usual extremely long bristles and hairs. Femora short, swollen. Tibiae dark brown.

Abdomen black, shining, with predominantly whitish short hairs laterally and white spots at sides of tergites 2–4. Hypopygium of moderate size. Lateral bristles mostly yellow; on apical segments they, as well as the hairs, are dark.

Length of body 9.5–13.5 mm., of wing 7–10 mm.

Females appear to be larger on the average than the males.

2 ♂♂, 3 ♀♀, 20.iv.1924, Eidsvold, Queensland (Bancroft), type male, labelled with a type label; 1 ♂, Jan.–Feb. 1923, Eidsvold, Queensland.

Type in the Division of Entomology Museum, C.S.I.R.O., Canberra.

Laphria dayi sp. nov., ♂, ♀

Belongs to the group with black legs, but with not absolutely black wings, easily distinguishable from L. modesta sp. nov. and L. mauroides sp. nov. by the presence of numerous, short bristles immediately above the scutellum, in the prescutellar area of the mesonotum.

Body black, shining. Head densely covered with a greyish dust, moustache area shining. Bristles of moustache very long, black, the lateral parts of the face covered with whitish

bristles and hairs. Moustache tubercle very well developed. Proboscis massive, short, acute, shining, black, depressed from above, not compressed laterally. On occiput about a dozen strong, black bristles.

Mesonotum shining, with some white spots on humeral calli, also beside them and at the sides of the mesonotum. Collare (pronotum) with a row of numerous black, short bristles. Pleurae also with whitish spots, but mesopleurae shining. Mesonotum bare, but there are three longitudinal rows of short, black hairs, and the prescutellar area is covered with numerous, long, erect hairs; area immediately above the scutellum with short black bristles. The tuft of long hairs in front of the halteres consists of black and whitish hairs. On margin of scutellum 8–10 long white hairs (reduced bristles). Wings dark, with colour saturated along the veins. First posterior cell rather broadly open. Fourth posterior cell very broad, slightly shorter than discal cell. Halteres yellow. Legs black, pulvilli brownish. Hairs on legs mostly whitish, the very long hairs usually present on tibiae are not very well developed in this species. All femora are very moderately swollen.

Postnotum strongly shining, almost silvery.

Abdomen strongly shining, nearly bare; on the sides of the tergites are some whitish hairs, and 1 black bristle laterally. On the sides of tergites 2–4 are whitish spots. Hypopygium of male not large, only slightly protruding.

Length of body 14.5–18 mm., of wing 10.5–15.5 mm.

New South Wales: 1 ♂, 14.ii.1928, National Park (Mackerras) (type), and 1 ♂, 1 ♀, same date and locality; 1 ♂, 20.ii. Gordon (D. F. Waterhouse); 1 ♂, 27.xii.1927, Dee-Why (M. Fuller); 1 ♂, 18.ii.1936, Killara (M. F. Day); 1 ♂, 3 ♀ ♀, 7.iv.1951, 17 mls. SSW of Bohena, Pilliga Scrub (Key & Chinnick). Western Australia: 1 ♂, 1 ♀, 30.xii. 1953, 12 mls. W. of York (J. H. Calaby).

Type in the Division of Entomology Museum, C.S.I.R.O., Canberra.

Laphria campbelli sp. nov., ♂

Belongs to the group of species with black legs; closely related to *L. mauroides* sp. nov., but having a distinct, bright yellow base to the wing.

Head as in *L. mauroides* sp. nov., third antennal joint also very broad, elliptical.

Mesonotum as in *L. mauroides* sp. nov., a pair of whitish spots beside the humeral calli, another pair at suture laterally, and a 3rd pair at the postalar calli. Hairs distributed irregularly on the mesonotum. A brush of thick short hairs on the underside at the apex of the hind tibiae is more strongly developed than in *L. mauroides*. First posterior cell is narrower at apex than in *L. mauroides;* only one-third of the width of the 2nd one, whereas in *L. mauroides* it is equal to one-half. Wings are distinctly narrower than in *L. mauroides*.

Abdomen as in *L. mauroides*.

Length of body 11–13 mm., of wing 8.5–9.5 mm.

1 ♂ (type), 12.iii.1957, Exp. area 3 mls. E. Pilot Hill, Bago Forest, Batlow, New South Wales. Phasmid Ecol. Exp. (T. G. Campbell); 1 ♂, same data and locality.

Type in the Division of Entomology Museum, C.S.I.R.O., Canberra.

Laphria burnsi sp. nov., ♂, ♀

Closely related to *L. bancrofti* Ric., but easily distinguishable by the reddish yellow abdomen in the male, and the reddish central half of the abdomen in the female.

Head as in *L. bancrofti* Ric., but moustache consists of distinct black bristles, not hairs. Facets near face are much larger than on the outside of the eye. Face occupying about one-fifth of head width. Palpi yellowish haired. Occiput predominantly yellowish haired, only on the upper part are there some long, black hairs.

Mesonotum as in *L. bancrofti* Ric., but bristles black in both sexes. Wings strongly darkened in their apical two-thirds, in the basal third almost hyaline. Hind femora very

swollen, especially in male.

Abdomen in male reddish, only the basal segment and genitalia deep black, shining. Hairs on 2nd and 6th tergites reddish, on 3rd–5th tergites black; these hairs are rather long and numerous, but depressed. Hypopygium very massive, rounded, and complicated in structure, longer than the 6th tergite. In the female the abdomen is black, but the central half is reddish, and covered with black hairs which camouflage the ground colour of the abdomen; last two tergites wholly reddish. The base of genital is also reddish but the remainder is black; hairs yellow.

This species is also very closely related to *L. variana* White, but its black anterior and middle femora permit it to be separated easily from that species, as the fore and mid femora of *L. variana* White are widely yellow in the basal part. The colour of the wing is also different from that of *L. variana;* the larger apical part is strongly separated from the
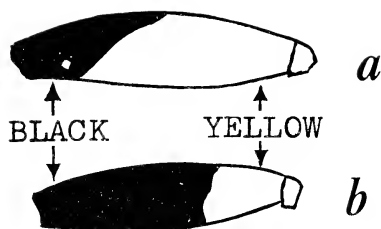
FIG. 6. *a*, Fore femora of *Laphria variana* White, female. *b*, Fore femora of *Laphria rufifemorata* Macq., female.

hyaline base, whereas in *L. variana* the entire wing is uniformly coloured with an intermediate intensity.

Length of body 13 mm., of wing 9 mm.

1 ♂ (type), 1 ♀, 11.xii.1949, probably in copula, Eubenangee, Nth. Queensland (A. Burns); 1 ♀, xi.1926, Meringa, Queensland (Goldfinch).

Type in the private collection of Mr. A. Burns, Melbourne.

Occurrence of *Protohydra leuckarti* in Puget Sound

Wolfgang Wieser[1]

SINCE THE HYDROZOAN *Protohydra leuckarti* Greeff has always been considered an animal of great taxonomic and morphological interest, its discovery on the Pacific coast of North America deserves notice. This is the first record of the species for the Pacific Ocean. It was reported once before from the Pacific area, from a lake—probably a brackish one —in Kamtchatka (Abonyi, 1929).

My specimens are derived from two sand beaches on Puget Sound in the state of Washington, viz., from "Golden Gardens," within the city limits of Seattle on the east side of the Sound, and from Vashon Island farther south in the Sound. The species occurs in the lower intertidal zone of the beaches

(from −1 to +3 feet), sometimes in considerable numbers. It was found in October 1955 and January 1956 at Golden Gardens, in May 1956 on Vashon Island. The sand is medium fine at the former locality, fine at the latter. A mechanical grain analysis of the two substrata gave the following results:

	Golden Gardens	Vashon Island
4760–2362μ....	10.9%	0.1%
2362–1190μ....	13.3	0.3
1190– 589μ....	44.9	2.7
589– 295μ....	26.8	19.1
295– 149μ....	3.9	61.7
<149μ....	...	16.1

The surface water of Puget Sound is of slightly reduced salinity; it varies from less than 27.5o/oo in April and May to 30o/oo in autumn months. This is true also for the central portion of Puget Sound. The water
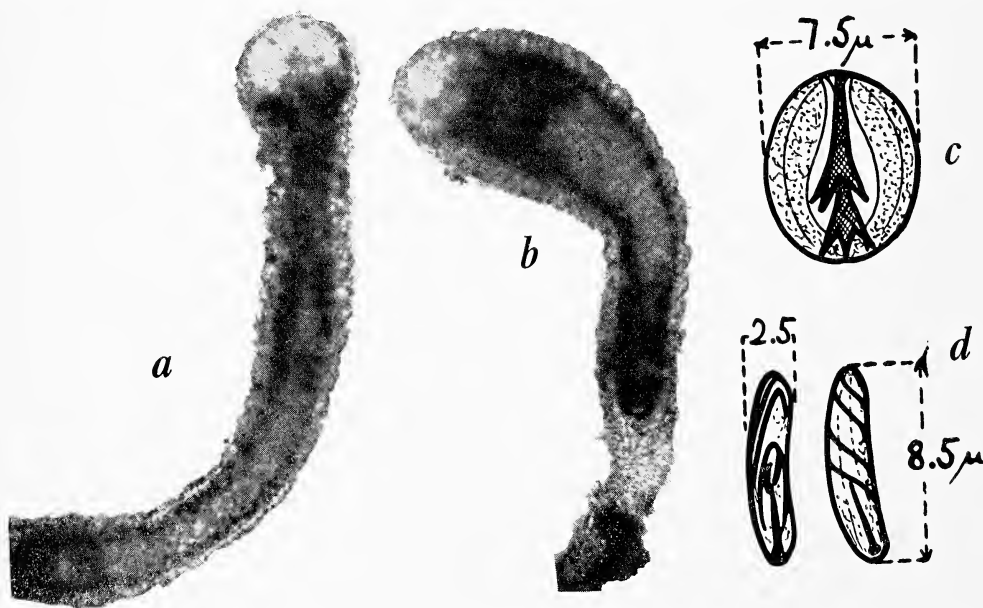
FIG. 1. *a* and *b:* Two different stages of contraction of the same specimen of *Protohydra leuckarti* (photomicrograph from life by Pat Dudley). Note the globular swelling at the anterior end in *a*. This is a typical stage after a wave of contraction has travelled through the animal from back to front. *c:* Stenotele (penetrant), *d:* isorhizas (glutinants), from an alcohol-fixed specimen.
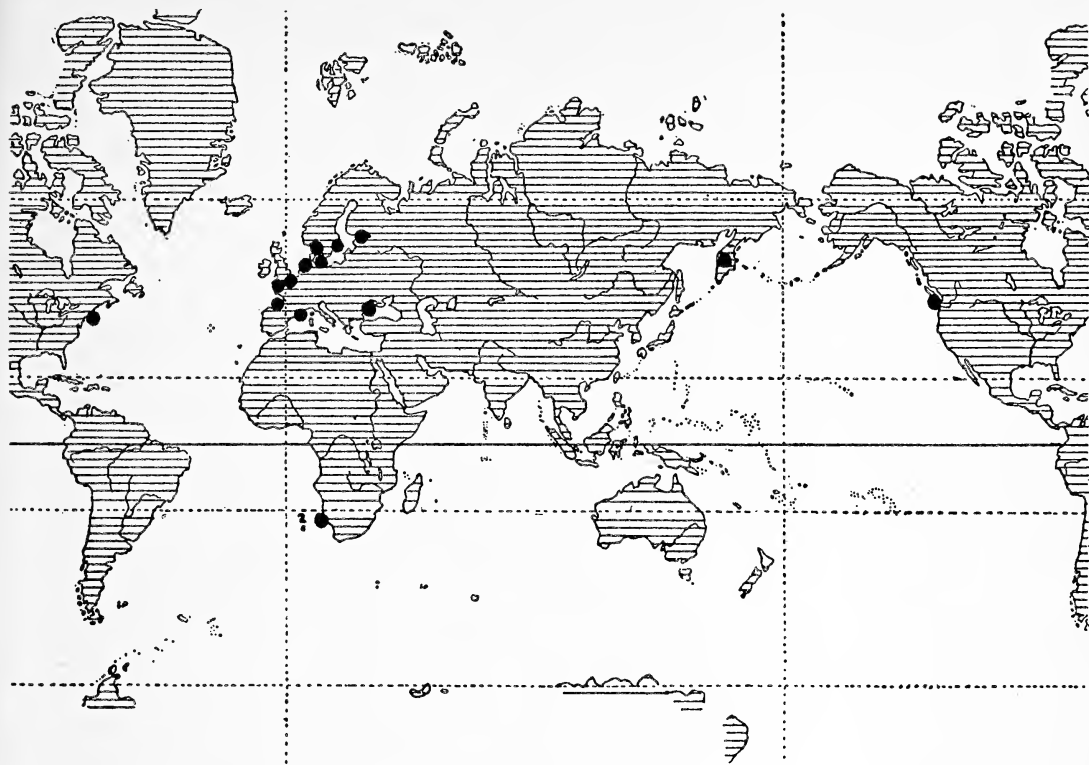
FIG. 2. Map of distribution of *Protohydra leuckarti*.

along the beaches is subject to greater variations in salinity due to the inflow of several rivers, but it never can be called brackish. Therefore, Ekman's statement (1953: 117) to the effect that *P. leuckarti* is a typical indicator of brackish water (that is, mesohaline, from 3 to 10⁰/oo) does not hold for this locality.

The temperature of the water is fairly stable the year round, varying from 8.5° in winter to 14° in summer. This, of course, applies to the central portion of the Sound only. The intertidal zone will be subject to greater extremes.

The fauna accompanying *P. leuckarti* is a typical sandfauna with gastrotrichs (*Turbanella* spp., *Macrodasys* sp., *Paraturbanella* sp.), cumaceans (*Cumella vulgaris, Lamprops krasheninikova*), many nematodes, etc. At Vashon Island, due to the finer substratum and the proximity of seaweeds, some representatives of a mud-fauna, e.g., *Corophium insidiosum* and *Leptochelia dubia*, occurred in the same habitat.

My specimens of *P. leuckarti* conform with previous descriptions. This is especially evident if the structure and size of the nematocysts, as shown in Figure 1*c, d*, are compared with the figures and data by Luther (1923), and Weill (1934).

In length the adult specimens varied between 0.7 and 2 mm., according to the state of contraction of the animal.

I have encountered copepods and nematodes in the body cavity of some of my species. Others were actually seen feeding on nematodes. In one case a *Protohydra* had begun to swallow a nematode about five times the length of the hydrozoan. By its violent movements the nematode had pierced the posterior end of its predator so that the latter appeared to be pulled like a sleeve over the prey. The body of the nematode was

covered with nematocysts that stuck to the cuticle.

Two species were sectioned, but there was no indication of gonads. Some specimens from Vashon Island, however, showed transverse fission. Although no zoogeographical conclusions can be drawn as yet, due to the absence of systematic studies in all parts of the world except the North European and, recently, the Mediterranean coast, I add a map (Fig. 2) with the distribution of *P. leuckarti* indicated. Recent information was contributed by Schulz (1950, 1952), Nyholm (1951), Valkanov (1947), Ruebush (1937), etc. The range of distribution makes it very likely that the species is cosmopolitan, as is already assumed by Nyholm.

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PACIFIC SCIENCE

A QUARTERLY DEVOTED TO THE BIOLOGICAL AND PHYSICAL SCIENCES OF THE PACIFIC REGION

Previous issue published February 3, 1958

CONTENTS

Distribution and Ecologic Aspects of Central Pacific Salpidae (Tunicata)[1]

JAMES L. YOUNT[2]

THE PRESENT REPORT is a continuation of a general salp study, the first section of which already has been reported (Yount, 1954). It concerns the distribution and ecology of the salps collected during two cruises by the "Hugh M. Smith" of the Pacific Oceanic Fishery Investigations of the United States Fish and Wildlife Service (referred to in the remainder of this report as POFI) in the central Pacific Ocean. Nineteen out of a total of 22 recognized world species were found in these collections.

Knowledge of the distribution of salps was reviewed by Traustedt (1885), Apstein (1894, 1906), Metcalf (1918), Ihle (1935), and Thompson (1948). Various other investigators have added to this general knowledge in regard to certain species. Certain points in regard to geographic distribution, however, needed clarification. Among these was an investigation of the usefulness of salps as indicator species of oceanic currents within the area of study. Moreover, knowledge of seasonal effects on salps, of the relation of salp abundance to the abundance of other zooplankton, and of the relation of salp abundance to physicochemical environmental factors was very limited. Thus studies were carried out, insofar as the available data would permit, in an attempt to elucidate these points. In addition, little information exists defining the actual role or position of salps in the plankton community (the niche as defined by Elton, 1927); consequently, the niche of the different salp species was investigated as thoroughly as possible.

ACKNOWLEDGEMENTS

MATERIALS AND METHODS

The animals used were taken from a large series of plankton captures made by POFI in an area that extended from 27° N. to 15° S. and from 176° W. to 155° W. In this area, the "Hugh M. Smith" made cruise 5 in June, July, and August of 1950, and cruise 8 in January, February, and March of 1951, thus permitting seasonal comparisons. The study of abundance and distribution was confined to cruises 5 and 8; of these cruises, all samples (51) from cruise 5, and 30 samples out of 106 from cruise 8, were studied.

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The total plankton data used here were reported by King and Demond (1953); Cromwell (1953, 1954) reported all hydrographic observations used here. As King and Demond stated, the plankton net descended obliquely to 200 meters, then made an oblique ascent to the surface. Thus the net strained, during approximately 30 minutes, a total of about 1,000 cubic meters of water. This net was described in King and Demond's report as being 1 meter in diameter, with a mesh width of 0.65 mm., but I should point out here that it was an open net. For this reason, vertical distribution of the captured animals is unknown.

All animals larger than about 5 cm. were removed from each POFI plankton sample (King and Demond, 1953). The sample was then divided into two equal portions, one of which was not used by POFI personnel. The latter portions were used for the present study. Therefore, in calculations where comparisons were necessary, salp numbers and volumes were estimated by doubling the figure obtained from each half sample. In addition, many of the removed salps larger than 5 cm. were examined and identified. Number determinations of salps were made by direct counting, whereas volume determinations of the salps were made for each plankton sample by means of water displacement in a graduated cylinder. In order to determine the relation between salp volume and volume of the other plankton in the same sample, the salp volume determinations were divided by the amount of water strained (taken from King and Demond) and compared with the total volumes of zooplankton, less salps, reported by King and Demond.

ABUNDANCE OF SALPS

Physicochemical Factors of the Environment

A study of the ecology of salps should consider all aspects of their environment such as food, enemies, and the distribution of physicochemical factors of the waters in which they are found. Of possible direct importance to them is the distribution of temperature, density, currents, salinity, and oxygen. On the other hand, distribution of light and of nutrient chemicals, factors which influence phytoplankton production, is probably only indirectly important to salps. Which among these are limiting factors for salps is almost wholly unknown.

In the open ocean, salinity is presumed not limiting because of its small variation, from about 34 to 36 °/oo. Salps seem to be absent from areas of very low or high salinity, such as may be found in certain waters. For example, Apstein (1906) reported no salps from the region off the mouth of the Congo River in Africa, a situation apparently related to the low salinity (30.4 °/oo) in the area; and Ihle (1935) noted that some species of salps were absent from the eastern part of the Mediterranean Sea, perhaps indicating a relationship to the high salinity (up to 40 °/oo off Syria).

In regard to temperature, also, little is known about limits of tolerance for the various species, although all salp species—except an antarctic form, *Ihlea magalhanica*—are found principally in warm regions of the ocean. Occasionally they are found in high latitudes, presumably carried there by current tongues, for example, in the Bering Sea (Metcalf, 1918), the Gulf of Maine (Bigelow, 1926), the North Sea (Fraser, 1949, 1954), and waters of southern Australia (Thompson, 1948). Salps have also been found at great depths (more than 1,000 meters) where the temperature was low (Apstein, 1906; Michael, 1918; Sewell, 1926, 1953; Leavitt, 1935, 1938). The limits of tolerance for both salinity and temperature in the various species are thus unknown and can only be inferred from reports of distribution.

Factors that influence variation in organic productivity must also be considered for a clear understanding of variation in salp abundance. Areas of maximum biological productivity are found in coastal waters, in temperate and higher latitudes, and in regions of upwelling. Productivity in these areas is based

chiefly on vertical mixing of the waters (Sverdrup, *et al.*, 1942: 785; Tait, 1952: 76; Harvey, 1955: 99) and additions of dissolved nutrients from the land (Künne, 1950: 57; Dakin, 1952: 7), which bring nutrients to the euphotic zone where they can be used. In temperate waters, vertical mixing and resultant enrichment are useful for production principally in the spring and fall; in midwinter the standing crop of organisms is low, due primarily to insufficient light intensity, while in midsummer the low standing crop is apparently the result of depletion of nutrients in the euphotic zone (Russell and Yonge, 1936: 246). In tropical waters, on the other hand, there is generally a low concentration of nutrients in the euphotic zone with an attendant low standing crop throughout the year, apparently because upper tropical waters (to a depth of about 300 meters) are characterized by a three-layer system—an upper warm layer, a transition layer, and a lower cool one— present during a large portion of the year. Thus sinking of decomposing substances from the surface layer to a depth below the transition layer results in a removal of nutrients from the euphotic zone until vertical mixing of the waters again brings the nutrients back.

The enrichment in the zone between about 2° N. and 5° S. in the area studied undoubtedly originates principally from vertical water movements; i.e., it probably does not originate in the Peru Current from the east. The phosphate and standing crops of the region studied probably also reflect, in small part, a horizontal movement of water from the east. No quantitative data on the westerly limits of the effects of the Peru Current are available, but considering the great distance involved, one can assume that the phosphate from upwelling in the Peru Current is utilized long before reaching the meridians studied. In other words, the water from the Peru Current has "aged" by the time it reaches these meridians, i.e., has moved far from the upwelling which initially enriched it (Steemann-Nielsen, 1954). However, since these waters of the

meridians studied are in a continuous state of upwelling they are "young," that is, they have a high concentration of nutrient chemicals, being more or less continuously replenished from below.

Another factor should be considered in regard to enrichment: phosphates probably affect salps only indirectly. As only plants are considered able to utilize dissolved nutrients such as phosphates for biological production, salps are probably affected by phosphates only by way of their food, which consists primarily of phytoplankters. Salps thus stand one trophic level away from the dissolved nutrients as shown by their trophic relationships: dissolved nutrients → phytoplankton (producers) → herbivorous zooplankton (primary consumers). Time, therefore, is required for the phosphates to be used by the phytoplankton in order that the primary consumers can be affected by the increased production. For this reason, it is possible that the salps captured at the same time would show little correlation, station to station, with the phosphates. However, the increased phosphate found in the region of upwelling is a zonal condition and thus not transient, and results in generally larger standing crops of plankton in this region (Cromwell, 1953; King and Demond, 1953).

Considering the above factors, then, one would expect increased availability of nutrients in the regions of upwelling and in other regions in which frequent vertical mixing occurs, such as in zones of shear at the edge of currents (the regions of "Ansammlungen" of Apstein, 1906), and in waters near island masses where vertical mixing and diffusion may occur as a result of eddies and where dissolved nutrients from the land may be added. Therefore, the a priori expectation for this study was that larger standing crops of salps would be related to those ecologic factors favorable to biological production.

One further subject—that of the sources of error to which the results are liable—should be discussed before a description of the meri-

dional sections is given. King and Demond (1953) described the possible errors in regard to the total zooplankton, and a large part of the following review is based on their report.

One source of error is from the fact that estimates of each plankton sample were made by doubling the figures obtained by direct measurement and counting of the half samples. In addition to the halving of each plankton sample, another source of error comes from the removal of organisms larger than 5 cm. from each of the samples. Undoubtedly this removal of large salps has considerably reduced the volume of capture at some stations.

Day-night variation was shown by King and Demond to have had considerable influence on the total zooplankton of cruises 5 and 8, but there was no important effect of this variate on salps, at least in the 0–200 meter layer. This is in agreement with the report of Apstein (1906), who considered that, in general, salps perform no diurnal vertical migrations. One species, *Thalia democratica*, however, was considered by Michael (1918) to migrate vertically as a result of temperature variations and reproductive behavior. Hardy (1936) and Fraser (1949) have given evidence that indicates a nightly movement toward the surface, but their tows were shallower than 200 meters.

Perhaps the most important source of error is the "patchy" distribution, both horizontally and vertically, of plankters in general. Nothing is known of the extent to which the variations in capture of the plankters is reliable: i.e., there is doubt as to whether there is a true ecologic difference between the capture at one station of 1 cc. of salps/1000m^3 and the capture at another station of 1.5 or 2 cc/1000m^3. Perhaps the difference is due simply to variation that could be expected from the method of capture alone or from the patchiness of the salps. A better way to minimize this error would be to take a series of plankton tows at each station so that an average could be obtained. This was imprac-

tical for the POFI cruises. In order to minimize patchiness, on cruises 5 and 8 only oblique tows were made, as the oblique tow has been regarded by Winsor and Clarke (1940) as well as by King and Demond (1953) as more efficient than either horizontal or vertical tows. By this oblique towing method, a large volume of water was strained; King and Demond assumed, therefore, that "variation in catch due to the uneven distribution of organisms is minimized" (p. 119). However, in view of the small volumes and numbers of salps observed occasionally, the actual population density may have been quite different.

The POFI cruises traversed three principal currents in the central Pacific: the westerly flowing North Equatorial Current which arises in part from waters of the California Current; the easterly Counter Current, with its source waters primarily from the neighborhood of the southern Philippine Islands and New Guinea; and the westerly South Equatorial Current fed from the Peru Current and the Gulf of Panama. Figures 1 and 2 show this region and the stations where the plankton samples were collected. For purposes of this report, the data from cruise 5, 172° W. are used as an example of the currents disclosed by a meridional section (cf. Fig. 4). The North Equatorial Current flows mainly westerly from the Hawaiian Islands (27° N., station 1) to the northern limit of the Counter Current at about 8° N., station 14; the easterly flowing Equatorial Counter Current (from about 8° N., station 14, to 4° N., station 18); and the westerly flowing South Equatorial Current (from about 4° N., station 18) to the southern limit of the section.

Since the surface phosphate concentration is associated with the stratification of the water, which is in turn primarily dependent on the temperature, the vertical sections for these two parameters are closely related. Because the vertical temperature sections are so revealing, they are used to describe the general ecologic features to be considered with
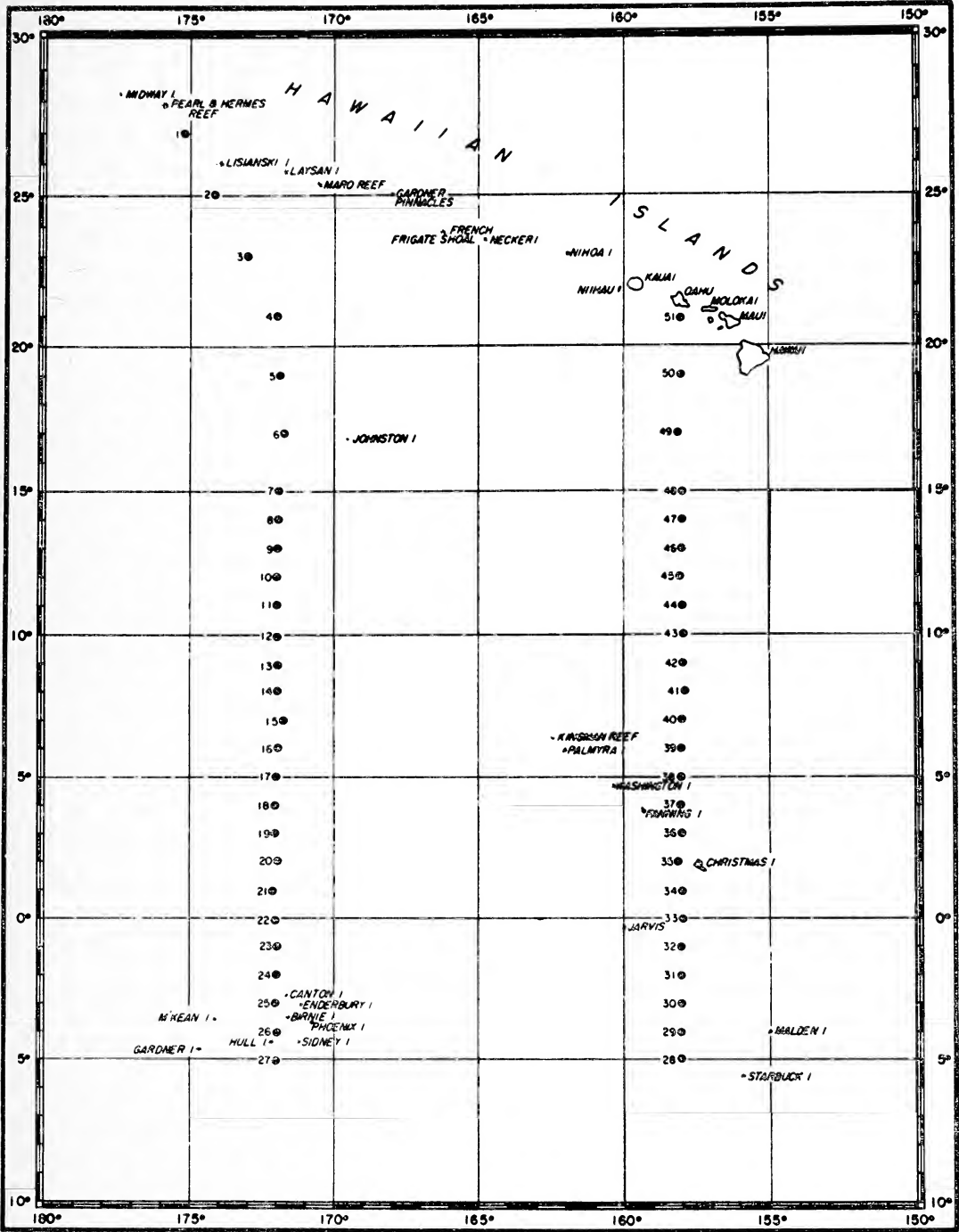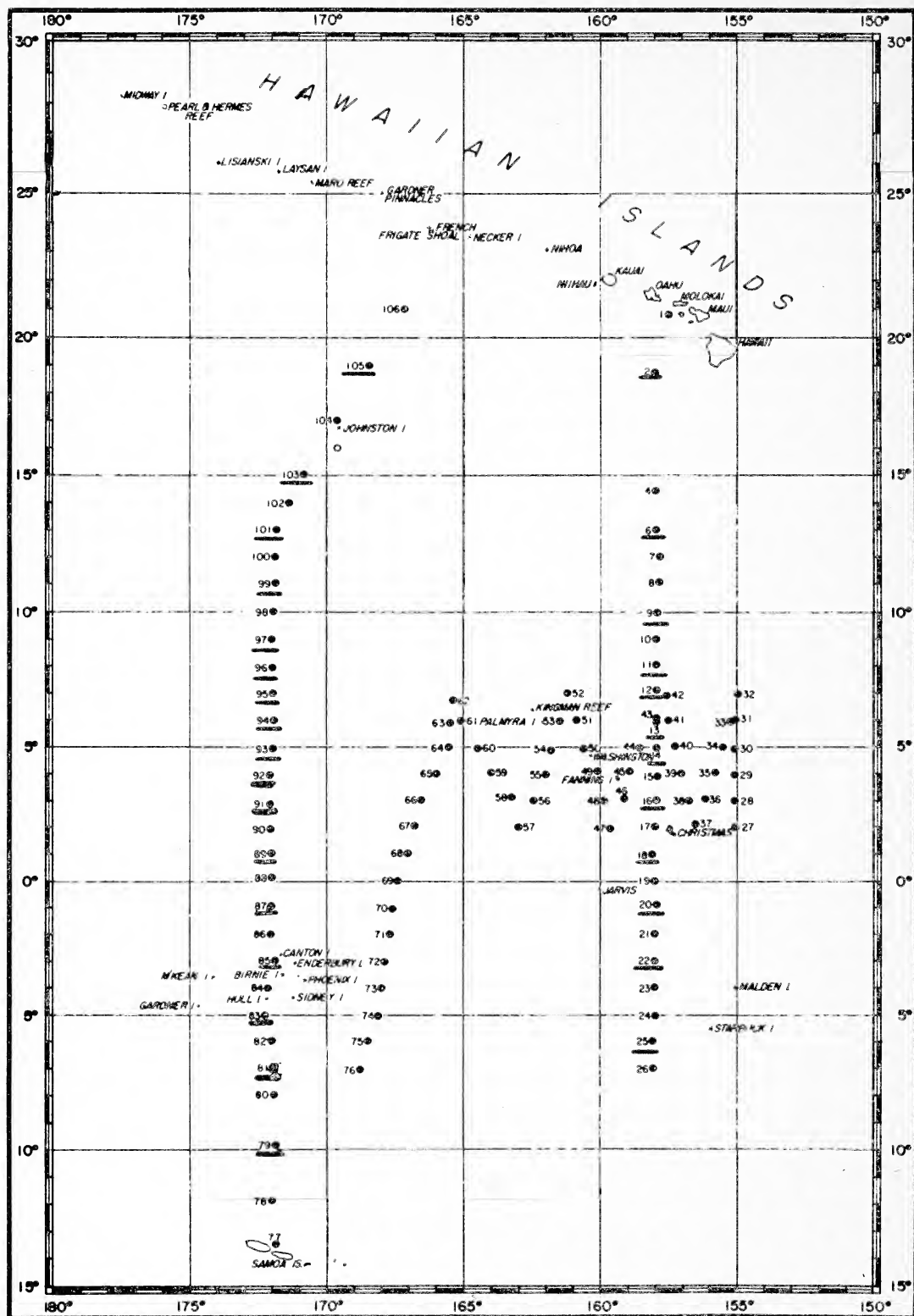
FIG. 1. "Hugh M. Smith," cruise 5; June–August, 1950. Numbers 1–51 indicate stations at which plankton tows and hydrographic observations were made. (After Cromwell, 1954.)

each of the meridional series of salp samples. It should be pointed out, however, that the distribution of the other determined factors — density, salinity, inorganic phosphates, and dissolved oxygen — is very similar on all meridians studied here (see Cromwell, 1954). The detailed descriptions of all parameters studied may be found in Cromwell (1953, 1954).

Considering the emphasis to be placed on temperature, it is desirable to describe its major variations. It was found (Cromwell, 1954) that temperature distribution in the North Equatorial Current was characterized by a relatively poorly developed thermocline. The region of the Counter Current (about 8° N. to 4° N.) was characterized by a gradual north-south sharpening of the thermocline and a deepening of this layer to the south. The northern part of the South Equatorial Current was characterized by a well-developed, deep thermocline in the region of upwelling. South of this region, the thermocline again became less well defined. Inspection of the temperature distribution (Cromwell, 1954, fig. 6) shows conical isotherms resulting from an upward transport of the cooler waters of the lower surface layer and upper thermocline from 1° N. to 2° S. This is associated with the wind-induced divergence and the attendant upwelling, as evidenced by the cooler temperature found at the surface.

As the histograms in Figures 3 to 6 show, the salps discussed herein were taken on two meridional sections during cruises 5 and 8 of the "Hugh M. Smith." The histograms show the observed variation of the total salp volume, total salp numbers, and the numbers of the commonest species, *Thalia democratica*, *Salpa fusiformis*, *Ritteriella amboinensis*, and *Cyclosalpa pinnata*. A typical section, cruise 5, 158° W., is discussed in detail and the remaining sections are compared with it.

The typical section (Fig. 3) shows that the majority of the relatively large volumes were

taken from 1° S. to 4° N., in or near the region of upwelling which was characterized by low temperature and a high phosphate value. Large volumes were also taken from 17° to 21° N., apparently due to the influence of the Hawaiian Islands.

Total numbers of salps (Fig. 3*a*) showed a very different distribution from that of total volume, as can be expected, since a few large specimens may greatly influence volume but not numbers. Inasmuch as *Thalia democratica* comprised the principal portion of the total numbers at most stations, it is discussed simultaneously with total numbers. The greatest numbers were taken in the region under influence of the upwelled waters but large numbers were also taken in waters far from this region (15°N.), a fact which may be explained by the presence of a current shear and/or eddies associated with the Hawaiian Islands. The large numbers taken at 4°, 5°, and 9° N. appear to be associated with the shearing effect at the southern and northern boundaries of the Counter Current. The majority of the small numbers occurred away from the upwelled region, in regions where the previously described layered system was well developed and the phosphates in the euphotic zone were low.

The other common species show a rather different distribution (Fig. 3*b*). *Salpa fusiformis* was most abundant near the region of upwelling. No substantial influence was shown by proximity to islands. *Ritteriella amboinensis* was taken in greatest numbers near the upwelling and in regions possibly influenced by proximity to islands. *Cyclosalpa pinnata* occurred only in small numbers; nevertheless, its principal occurrence was in the region of upwelling in the South Equatorial Current. It does not appear to have been influenced by other factors examined.

The section of cruise 5, 172° W. (Fig. 4), is characterized by a more general meridional

FIG. 2. "Hugh M. Smith," cruise 8; January–March, 1951. Numbers 1–106 indicate stations at which plankton tows and hydrographic observations were made. The underlined numbers represent stations examined for the present study. (After Cromwell, 1954.)
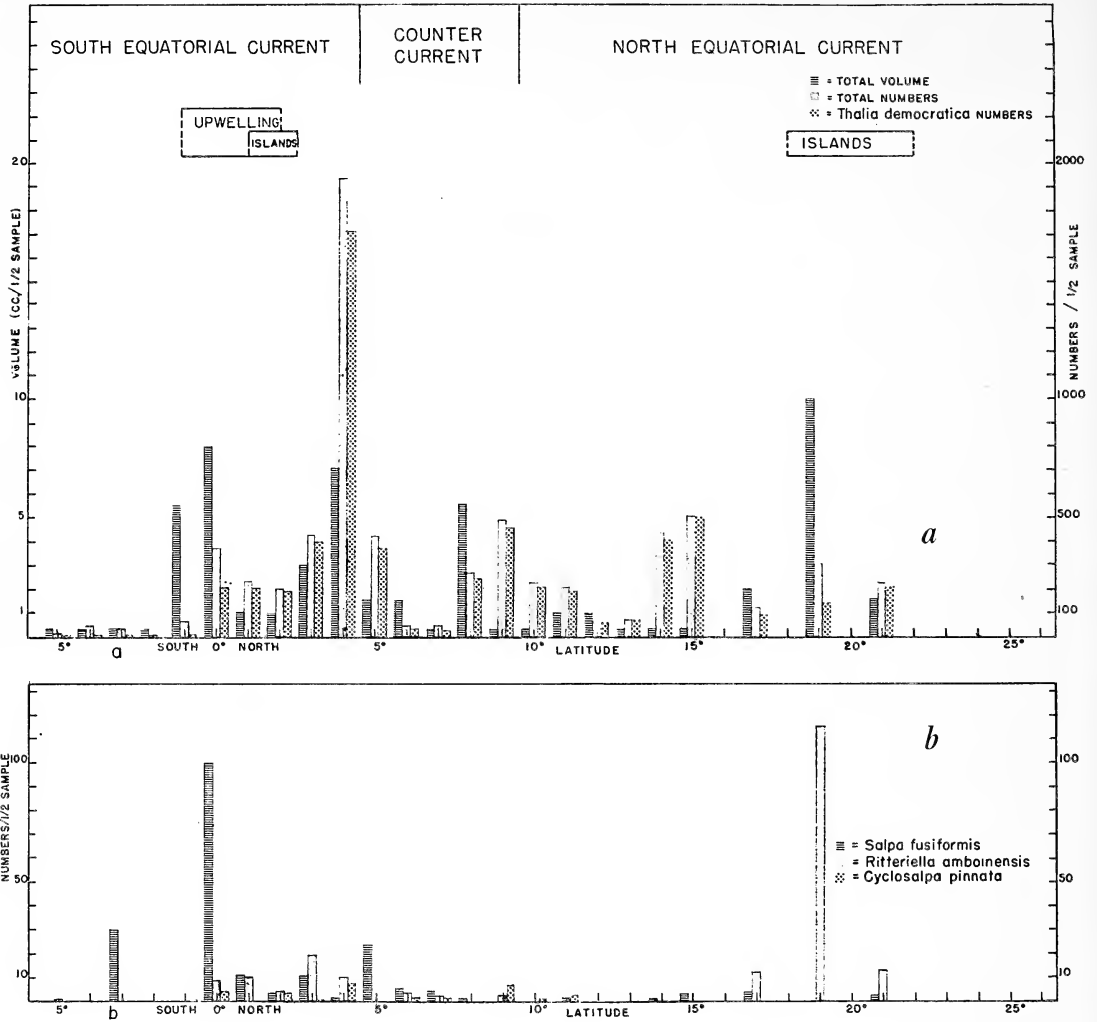
FIG. 3. Cruise 5, 158° longitude. *a*, Relationship of total salp volume, total salp numbers, and numbers of *Thalia democratica* to major currents, upwelling, and island masses. Limits of currents, upwelling, and islands are approximate. *b*, Relationship of the other common species, *Salpa fusiformis*, *Ritteriella amboinensis*, and *Cyclosalpa pinnata* to major factors listed in *a*.

distribution with indications of increased volumes near the equator, near the current shear at the margin of the Counter and North Equatorial Currents, and in waters near the Hawaiian Islands. Relatively great total numbers and numbers of *Thalia democratica* were taken near the region of upwelling and in waters near the Hawaiian Islands. The abundance of the other species shows little apparent relation to the ecologic factors being considered, but there was a tendency to

greater numbers in the region of upwelling.

In regard to the section of cruise 8, 158° W. (Fig. 5), the distribution of the volumes appears to be random, showing little apparent relation to the ecologic factors examined except in one instance (10° N.), where a relatively large volume was taken in the region of current shear between the margins of the Counter and North Equatorial Currents. The distribution of total numbers and of numbers of the common species also showed little
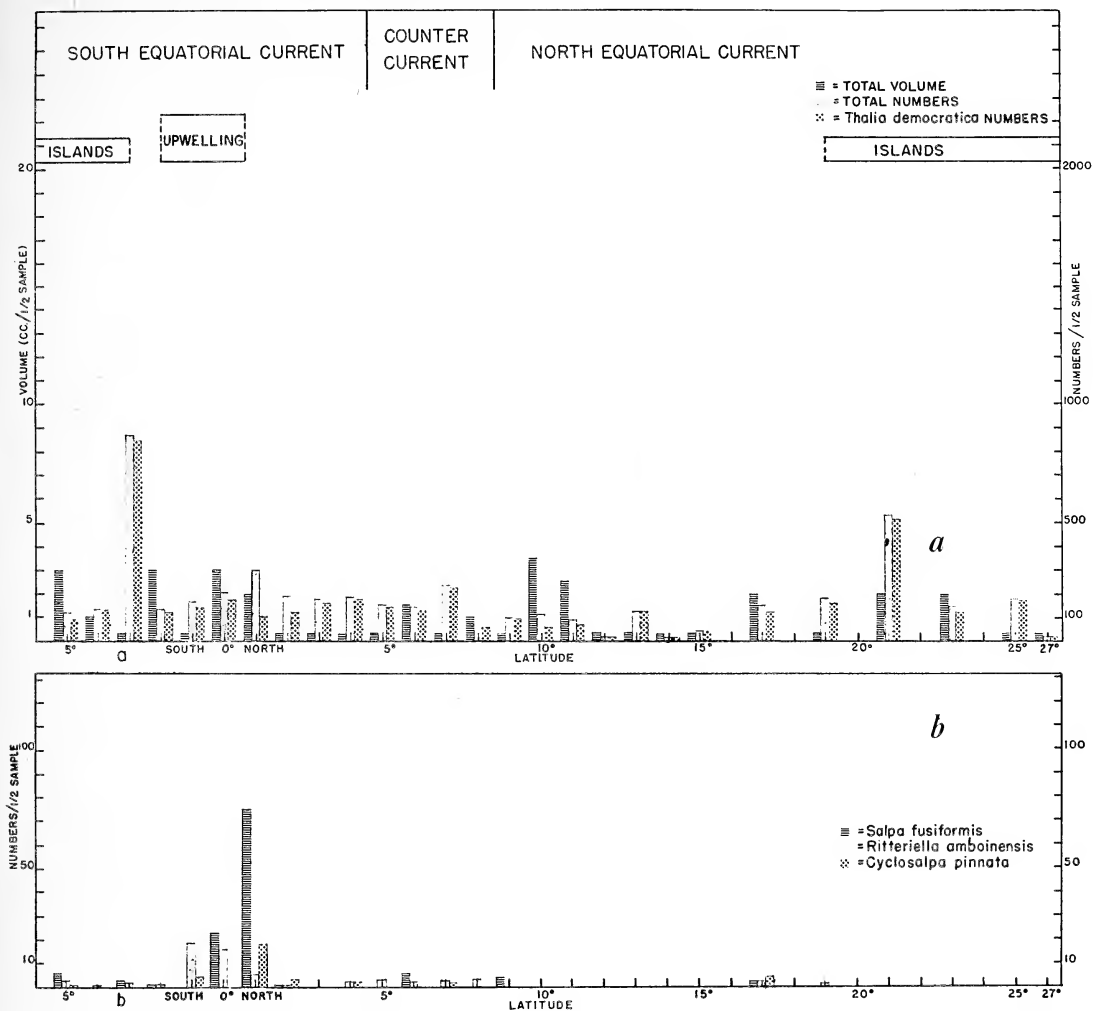
FIG. 4. Cruise 5, 172° W. longitude. *a*, Relationship of total salp volume, total salp numbers, and numbers of *Thalia democratica* to major currents, upwelling, and island masses. Limits of currents, upwelling, and islands are approximate. *b*, Relationship of the other common species, *Salpa fusiformis*, *Ritteriella amboinensis*, and *Cyclosalpa pinnata* to major factors listed in *a*.

relationship to the ecologic factors examined.

The section of cruise 8, 172° W. (Fig. 6), shows that relatively large volumes were taken in the region of upwelling and near the current margins of the Counter and North Equatorial Currents. Relatively great numbers were taken also in these regions, with a predominance of the greater numbers near the region of upwelling.

In summary, it can be stated that most of the greater volumes and numbers of salps taken on these longitudes were taken either within or near the cool enriched upwelled waters, in regions possibly influenced by current shear, or in regions in which there was a possible island influence on their abundance. The effect of temperature on salp abundance is undoubtedly only indirect within the ranges found on these cruises, inasmuch as cool non-upwelled waters contained, in general, relatively few salps except near islands. This predominance of greater volumes in regions of upwelling occurred on cruise 5, 158° and 172° W., and cruise 8, 172° W. The abundance

of the salps on cruise 8, 158° W., appeared to be unrelated to upwelling, however. There appears to have been an influence of island proximity on salp abundance on cruise 5, 158° and 172° W. It apparently had no effect on the abundance at either longitude of cruise 8. The influence of shearing at current margins apparently affected salp abundance on cruise 5, 158° W., and cruise 8, 158° W. Other than these, no relationships of salps to ecologic factors can be determined from the available data.

Relative Abundance of Species

The most numerous species of salp in the POFI collections is *Thalia democratica*. In the central Pacific Ocean, therefore, the statement of Apstein (1906) that this species is the commonest salp in warm water holds true. Similarly, in the East Indies (Ihle, 1910), the Philippines (Metcalf, 1918), the Great Barrier Reef lagoon (Russell and Colman, 1935), and southeast Australia (Thompson, 1948), *T. democratica* is the commonest species found. However, it was reported by Ritter (1905) as
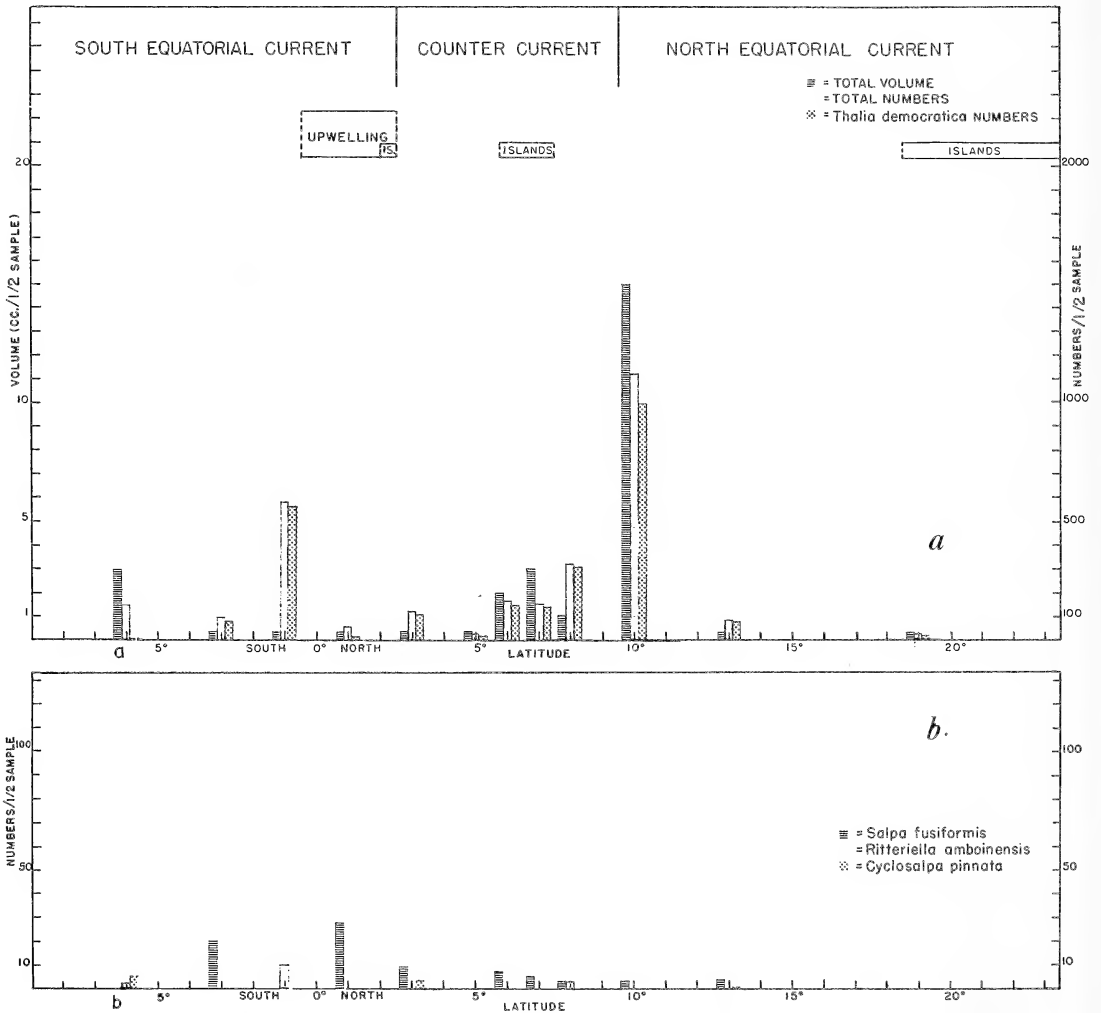

FIG. 5. Cruise 8, 158° W. longitude. *a*, Relationship of total salp volume, total salp numbers, and numbers of *Thalia democratica* to major currents, upwelling, and island masses. Limits of currents, upwelling, and islands are approximate. *b*, Relationship of the other common species, *Salpa fusiformis*, *Ritteriella amboinensis*, and *Cyclosalpa pinnata* to major factors listed in *a*.
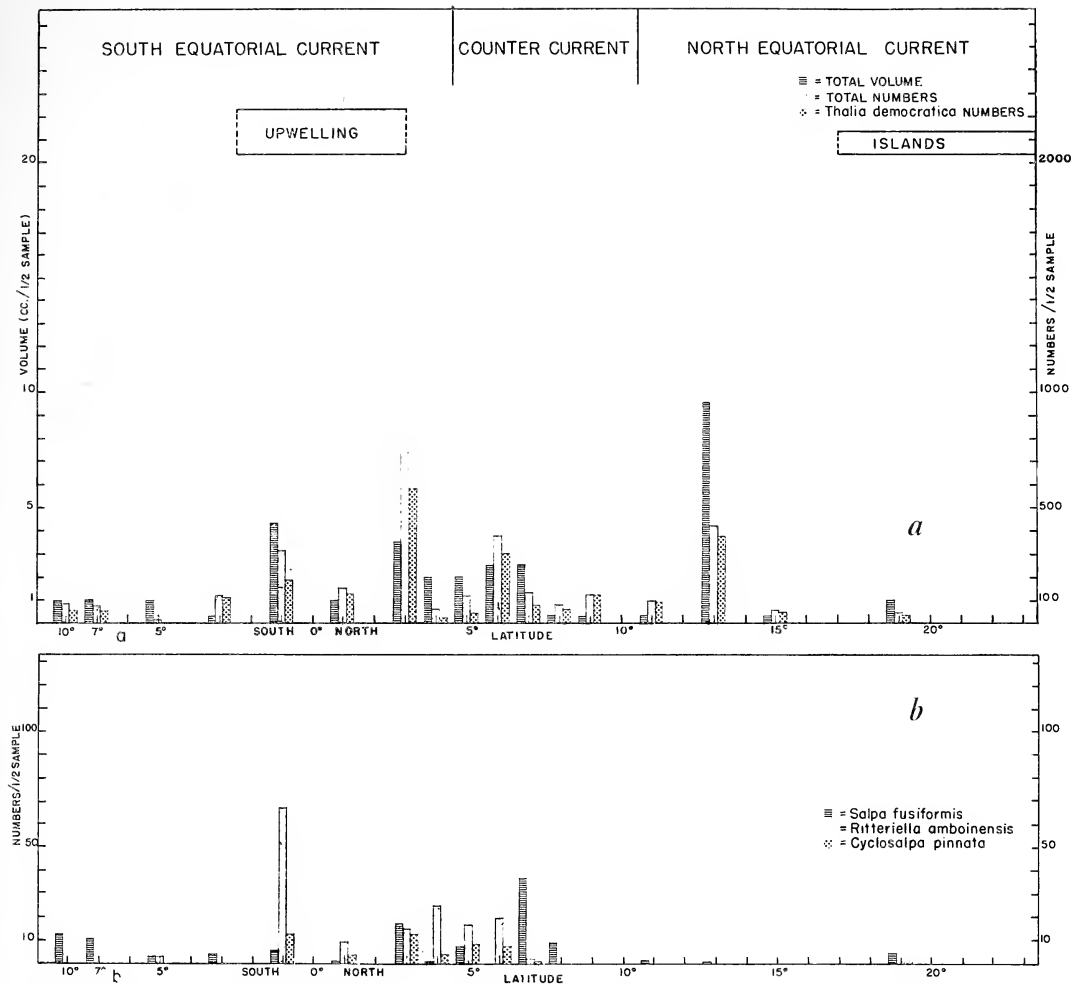
FIG. 6. Cruise 8, 172° W. longitude. *a*, Relationship of total salp volume, total salp numbers, and numbers of *Thalia democratica* to major currents, upwelling, and island masses. Limits of currents, upwelling, and islands are approximate. *b*, Relationship of the other common species, *Salpa fusiformis*, *Ritteriella amboinensis*, and *Cyclosalpa pinnata* to major factors listed in *a*.

being less abundant than *Salpa fusiformis* off the coast of California; this is perhaps a result of the lower temperatures in California waters.

RELATIVE IMPORTANCE OF DOMINANT SALP
SPECIES IN THE CENTRAL PACIFIC

Frequency of occurrence by station

Cruise 5	Cruise 8
1. *Thalia democratica*	*Thalia democratica*
2. *Ritteriella amboinensis*	*Salpa fusiformis*
3. *Salpa fusiformis*	*Ritteriella amboinensis* and *Cyclosalpa pinnata*

Numerical ranking of species

1. *Thalia democratica*	*Thalia democratica*
2. *Salpa fusiformis*	*Traustedtia multitentaculata*
3. *Ritteriella amboinensis*	*Salpa fusiformis*

Frequency of dominance by volume

1. *Iasis zonaria* and *Ritteriella amboinensis*	*Ritteriella amboinensis* and *Thalia democratica*
2. *Thalia democratica*	*Salpa fusiformis*

The chief salp component by volume in the central Pacific varies irregularly at the different stations. As volume is difficult to determine precisely, especially when there are few specimens of small species, volumes were determined to the nearest cubic centimeter and the chief component species was estimated by visual inspection. In some samples no one species predominated but usually one species predominated volumetrically; the same species or a different one might predominate numerically. The chief component species by volume may be a single specimen of a large species or a few specimens of a medium sized species, which may predominate over even large numbers of smaller species such as *T. democratica*. Inasmuch as specimens larger than 5 cm. were removed from the samples before the present study, the volumetric data may be incorrect for some stations, although, as King and Demond stated, these larger specimens were infrequent.

Comparison of Salp Abundance with Total Plankton Abundance

King and Demond (1953) have reported on the total plankton of cruises 5 and 8 by volume and numbers per cubic meter of water strained. The original numerical estimates and volume determinations were made available through the courtesy of Mr. King and the salp percentages discussed here were calculated from them.

Salps comprised more than 50 per cent of total plankton by volume at only one station (50) of cruise 5 (54 per cent); the highest percentage by number made up by salps was 9.1 per cent, at station 48 of cruise 5. On cruise 8, salps amounted to more than 50 per cent of the total volume at stations 9 (58 per cent) and 101 (65 per cent); the highest percentage by number was 4.1, at station 9.

These results, combined with the numerical percentage estimates of tunicates as compared with other zooplankters by King and Demond, show that tunicates in general play a relatively small numerical role in the central

Pacific plankton, but that salps in particular may attain a substantial volume as compared with other plankters. Ordinarily, however, salps play a rather minor role both volumetrically and numerically. Thompson (1942) stated, in reference to southeastern Australian waters, "Tunicates . . . comprise, next to Crustacea, the chief portion of the zooplankton," and, "Tunicates (chiefly salps) are the only other group which frequently predominates . . .," with a monthly average percentage of 25.4 as compared to 62.5 per cent for Crustacea. Thus, although the methods of capture are not strictly comparable, there is evidently a rather pronounced difference in the composition of the plankton between the central Pacific and southeastern Australian waters.

By using the methods described in Snedecor (1946, chap. 7), correlation coefficients were calculated to determine the relationship between salp numbers and zooplankton numbers (less salps) and salp volume and zooplankton volume (less salps) for cruises 5 and 8. In order to make use of salp volumes that measured less than 1 cc., such volumes were given an assumed measure of 0.5 cc. in the calculations. Neither correlation coefficient was significant for numbers or volumes of these cruises. From the evidence based on these cruises, then, there is no significant mutual relationship between salp and zooplankton numbers or volumes.

Comparison of Salp Abundance in the Central Pacific with Other Regions of the Pacific

It is impossible to make accurate quantitative comparisons between the plankton of different regions unless equipment and methods of capture are standardized. Unfortunately such optimal conditions have never been met. Nevertheless, as salps are relatively large animals and thus are taken by the commonly used nets, an attempt is made here to compare the salps of the central Pacific to those of the Great Barrier Reef lagoon as reported upon by Russell and Colman (1931, 1935), the only Pacific investigators who have

listed salps and other zooplankters by station and numerical frequency. Such a comparison is made more reliable by the fact that Russell and Colman used a 1-meter coarse international silk townet, which has an approximate mesh width of 0.42 mm.; the 1-meter nets used by POFI have a mesh width of 0.65 mm. (King and Demond, 1953). In addition, Russell and Colman towed their nets obliquely at each station for approximately a half hour, as was done for the POFI collections.

The chief difficulties with such a comparison are: (1) the amount of water strained was not computed by Russell and Colman and thus estimates of relative abundance of the plankton are only approximate; (2) volumes of the different groups of plankters were not determined for the Great Barrier Reef collections and thus, number of organisms, a relatively poor measure, offers the only means of comparison; and (3) the depth to which the POFI tows were made was approximately 200 meters, whereas those of the Great Barrier Reef Expedition were made to approximately 30 meters.

Russell and Colman (1935) listed the tunicates which occurred in oblique tows with the 1-meter coarse silk townet by species, reproductive form, and numerical frequency at 59 stations of the Great Barrier Reef lagoon. Comparison of these data with the data from the central Pacific reveals some striking differences. Only 6 salp species (4 with the coarse silk townet) were captured in the Barrier Reef lagoon, whereas 19 (16 on cruises 5 and 8) were captured in the central Pacific. *Thalia democratica* was by far the most numerous and frequently occurring species (80,987 specimens at 39 Barrier Reef stations), as it also was in the central Pacific. The fact, however, that *T. democratica* was lacking from fully 20 of the 59 Barrier Reef stations is surprising when compared with the POFI collections, where it was absent at only 2 out of 81 stations examined. In addition, this species was occasionally much more numerous in the Barrier

Reef lagoon than in the central Pacific (maximum numbers at one station of 17,000 and 3,440, respectively).

The other species found in the Great Barrier Reef lagoon rank among the relatively less common and infrequently occurring species in the central Pacific: *Brooksia rostrata* occurred in the Barrier Reef at 10 stations out of 59 (117 specimens), whereas in the POFI collections, it occurred at 24 stations out of 81 (259 specimens); 111 specimens of *Pegea confoederata* occurred at 8 stations out of 59 in the Barrier Reef, whereas 185 specimens occurred at 12 stations out of 81 in the central Pacific; *Weelia cylindrica* occurred at 13 stations (53 specimens) out of 59 from the Great Barrier Reef, whereas it occurred at 23 stations out of the 81 POFI collections examined (259 specimens). With the exception of *T. democratica*, the most numerous and frequently occurring species in the POFI collections, *Salpa fusiformis, Ritteriella amboinensis, Cyclosalpa pinnata*, and *Traustedtia multitentaculata*, did not occur at all in the Great Barrier Reef collections. All of these species, however, occur in oceanic Australian waters (Thompson, 1948).

Another striking difference between the collections from the Great Barrier Reef and those from the central Pacific is the large number of stations from the former at which no salps occurred (15 out of the 59 listed), whereas in the POFI collections, salps occurred at all 81 stations examined. In addition to the 59 tunicate-containing stations listed by Russell and Colman, there were 9 other collections made, which contained no tunicates.

On examining their data, another difference becomes evident; that is, a maximum of 17,003 specimens of salps (almost all *T. democratica*) was captured at one station, whereas the maximum number at any one station in the POFI collections was 3,864 (chiefly *T. democratica*). The maximum number of salp species taken with the coarse silk townet at any one station in the Great Barrier Reef,

however, was only 4; in the POFI collections, the maximum number of species at any one station was 9, more than twice the maximum number from the Barrier Reef.

In summary, then, bearing in mind the difficulties of quantitative comparisons, the chief differences between the Salpidae of the Great Barrier Reef lagoon and of the central Pacific Ocean, based on limited captures, are as follows: (1) the numbers of species found are much fewer as a whole in the Great Barrier Reef than in the central Pacific; (2) the maximum numbers of species present at any one station are much fewer in the Barrier Reef than in the central Pacific; (3) the numbers of individuals at any one station are often much greater in the Barrier Reef than in the central Pacific; (4) salps are more highly sporadic in distribution in the Barrier Reef than in the central Pacific, even being entirely absent from many stations, whereas they are present in all the POFI collections; (5) the most numerous and frequently occurring species, *T. democratica*, is the same in the two areas, but the species ranking next numerically and in frequency of occurrence are entirely different. Species other than *T. democratica* found in the Barrier Reef lagoon are relatively sparse and infrequent in the central Pacific collections, while the ranking species, other than *T. democratica*, of the central Pacific are wholly lacking from the Barrier Reef collections, although they occur offshore in the Australian region. These differences probably reflect chiefly the widely differing ecologic conditions between a neritic and an oceanic environment.

DISTRIBUTION OF SALPS

Geographic Distribution

Almost all investigators of planktonic animals have concurred with Giesbrecht's observation that, ". . . the epipelagic high-oceanic fauna may be divided into three main zoogeographical regions: a warm-water and a northern and a southern cold-water zone" (Ekman, 1953). This is true of the Salpidae except for the fact that there are no species confined to northern cold water. Therefore, it appears that water temperature is the primary limiting factor in the distribution of salps.

The majority of salps are cosmopolitan warm water plankters, although they may be carried into high latitudes from time to time. Only *Ihlea magalhanica*, *Thalia longicauda*, *Helicosalpa komaii*, and *Cyclosalpa strongylen-teron* have been reported as restricted to certain oceanic regions. According to Apstein (1894, 1906) and Thompson (1948), *I. magal-hanica* is restricted to the cool waters of the southern hemisphere; this is also true of *T. longicauda* according to Apstein, but Sewell (1953) reported one specimen from the northern Arabian Sea. *H. komaii* has been reported only from Japan (Komai, 1932) and the central Pacific (Yount, 1954), and *C. strongy-lenteron* only from the eastern Pacific (Berner, 1955), but both probably will be found to occur in the Indian and Atlantic oceans as well. Table 1 lists salp distribution by species as reported by Pacific investigators.

The remaining species of salps have been reported from the Atlantic, Indian, and Pacific oceans, except for *Ihlea punctata*, which has not yet been found in the Indian Ocean although it probably occurs there. Even the continents of South America and Africa do not prevent the transport of salps from one ocean to another, inasmuch as Herdman (1888) reported *Iasis zonaria* and Apstein (1906) listed *Salpa maxima* and *S. fusiformis* from the Straits of Magellan, and Apstein (1906) showed that *S. maxima*, *S. fusiformis*, *Metcalfina hexagona*, *Thalia democratica*, *T. longicauda*, *Pegea confoederata*, *Ia. zonaria*, and, of course, *Ih. magalhanica* had been captured at the region of the Cape of Good Hope or in more southerly waters. Salps are carried far into northern waters also (see Ihle, 1935), but probably cannot be carried alive into the Arctic Ocean.

With the exception of the four species mentioned above, then, it can be stated that the Salpidae is a family of cosmopolitan

TABLE 1

DISTRIBUTION OF SPECIES OF SALPIDAE (EXCEPT *I. magalhanica* AND *T. longicauda*)

SPECIES	ATLANTIC	INDIAN	JAPAN	PHILIP-PINES	EAST INDIES	AUS-TRALIA	N. E. PACIFIC	CENTRAL PACIFIC	EAST PACIFIC
Cyclosalpa pinnata....	+	+	+	+	+	+	+	+	−
C. affinis...........	+	+	+	−	−	+	+	+	+
C. floridana.........	+	+	−	−	+	+	−	+	−
C. bakeri...........	+	+	+	+	+	+	+	+	+
C. strongylenteron	−	−	−	−	−	−	+	−	+
Helicosalpa virgula...	+	+	−	−	−	+	−	+	−
H. Komaii..........	−	−	+	−	−	−	−	+	−
Brooksia rostrata.....	+	+	−	+	+	+	−	+	−
Ihlea punctata......	+	−	+	−	+	−	−	+	−
Salpa fusiformis......	+	+	+	+	+	+	+	+	+
S. maxima..........	+	+	+	+	−	+	+	+	+
Weelia cylindrica....	+	+	+	+	+	+	+	+	+
Ritteriella amboinensis.	+	+	+	+	+	+	−	+	−
R. picteti...........	+	+	+	−	+	+	+	+	+
Metcalfina hexagona..	+	+	−	+	+	+	−	+	+
Thetys vagina.......	+	+	+	+	+	+	+	+	+
Pegea confoederata....	+	+	+	+	+	+	+	+	+
Traustedtia multitentaculata...	+	+	+	−	+	+	−	+	−
Thalia democratica...	+	+	+	+	+	+	+	+	−
Iasis zonaria........	+	+	+	+	+	+	+	+	+

oceanic plankton organisms in the circum-global warm water zone.

Seasonal, Latitudinal, and Longitudinal Variation

Cruise 5 was carried out during June, July, and August of 1950, the northern summer, and cruise 8 was carried out during January, February, and March of 1951, the northern winter. A comparison of the two cruises should reveal seasonal variations, if any are present; therefore, an analysis of variance was calculated to determine seasonal differences. Longitudes and latitudes were analyzed simultaneously with seasons by the method described by Snedecor (1946: 304–309). Volumes were used as the variate rather than numbers, as volume is a better measure of the organic material in a plankton tow.

King and Demond (1953), who studied the total zooplankton volumes on cruises 5 and 8, demonstrated no significant first- and second-order interactions and no significant differences between longitudinal means, but did demonstrate significant differences between the means for seasons and for latitudes: No significant differences for the salp volumes, however, were demonstrated between either of the means for longitudes, for seasons, or for latitudes. Neither are there significant differences in the first- and second-order interactions, except that between longitudes and seasons. Therefore, there is probably ($P = 0.03$) an interaction between longitudes and seasons that produced the observed differences in volumes of salps at the 11 compared latitudes. I am unable to offer any conjectures to explain this interaction; it must be borne in mind, however, that the analysis is based on a few samples and that the variation in distribution of plankters, as well as the limited sampling by towing, could easily distort the resultant picture. This analysis supports the conclusion noted earlier under the comparison of volumes of salps and of the remaining zooplankton, i.e., that variation in salp volume does not necessarily relate to that of the total zooplankton, and was very different in the samples studied.

Relationship of Salps to Oceanic Currents

Comparison of the species at each station of cruises 5 and 8 (at the latitudes of Figs. 1 and 2, exactly listed by King and Demond, 1953), with the current system of the central Pacific (Cromwell, 1954) showed that there were only three species of salps found in but one current on these cruises. On cruise 5, 172° W., for example, *Cyclosalpa bakeri* and *Ihlea punctata* were found only in the South Equatorial Current. Examination of the distribution of these species on other longitudes and cruises, however, shows that they were found at some station in all other currents as well. This is true also of most other species, as they occurred in one longitude or another or on one cruise or another in all of the principal currents. Only three species were restricted in the central Pacific, *Cyclosalpa affinis*, *C. floridana*, and *Metcalfina hexagona*, the first and last of which occurred in only one current; *C. floridana* occurred in only two currents. *C. affinis* occurred at no other station of the two cruises and only three specimens were captured. It is thus an uncommon species in the POFI collections studied, and probably cannot be considered as an indicator of this current. *M. hexagona* was also captured at only one station on only one cruise, but occurred in fair numbers (43 specimens). On other cruises, however, it is not an extremely rare species, since in the collections of animals larger than 5 cm. from all POFI cruises, it occurs in at least five samples. It cannot be considered an indicator species, then, on the basis of only one record on one cruise, particularly since only 32 stations of cruise 8 were examined. *C. floridana* was also a relatively uncommon species on these cruises and thus cannot be regarded as an indicator species.

Ihlea magalhanica, a species not found in the POFI collections, has been considered a probable indicator species of colder water advancing northerly in the Australian area (Thompson, 1948). Thompson stated that *Ih. magalhanica* "is one of the salp species which has a low tolerance of warm water conditions," and that it "will therefore probably be useful as an indicator of any northern extension of the colder type of water conditions which may from time to time occur." In the same report, however, he stated, "there is . . . no evidence of a genuine cold water influence, even in Tasmanian waters, although in the latter region species which are characteristic of warm-temperature waters as well as of circumtropical waters are those most usually found (e.g., *Ihlea magalhanica*, *Iasis zonaria* and *Thetys vagina*)." *Ih. magalhanica* was earlier reported by Apstein (1894, 1906) in the Antarctic, westerly and southwesterly of the southern point of Africa, and in the Straits of Magellan, in water with a temperature range from 0° to 12.3° C. Thompson (1948), however, reported the temperature range of this species as between 11.6° and 22.25° C. This species, therefore, should perhaps be regarded as a eurythermal, rather than a stenothermal, cool water form and its usefulness as an indicator of cold water currents perhaps is much less than was thought previously. Its presence in water with a temperature of 22.25° C. may be exceptional, i.e., it may have been transported into such water but may not be long viable there, or the animal(s) may have been actually in a deep cool layer of water at this station. Thompson did not explain the situation, however.

Therefore, it can be stated that all salps captured on cruises 5 and 8 can be expected to occur in all currents in warm latitudes and that they are not satisfactory indicator species for these latitudes. Three uncommon species might possibly be true indicator species, but this is doubtful.

ECOLOGICAL NICHE OF SALPS

When one contemplates niches in the marine plankton community, it becomes clear that there are relatively fewer niches in the plankton than there are in the benthos or in land communities ("The 'niche' of an animal means its place in the biotic environment, *its*

relations to food and enemies," Elton, 1927: 64). For example, in the warm water epipelagic zone, the species are remarkably similar the world over (this is true of salps and it is undoubtedly true of other plankters as well); but even an oceanic island, such as Oahu for example, doubtlessly possesses many times more species of organisms than the plankton of the whole, vast epipelagic zone in the warm water belt of the world. This observation, I think, reflects the general paucity of niches and habitats in the pelagic oceanic environment, due most likely to the remarkable uniformity of the physical conditions and to the lack of shelter there.

The Salpidae is one of the many groups of planktonic filter feeders; salps feed by straining the water which passes through their body cavities by means of mucus strings secreted chiefly from the endostyle (see Ihle, 1935, 1937–39). Notwithstanding differences in structural and physiological mechanisms associated with filter feeders, they catch and consume, in general, the same organisms as other pelagic tunicates (pyrosomids, doliolids, and to some extent appendicularians), some pteropods, some copepods, and perhaps other constituents of the plankton, since the food of all these organisms is captured by simply filtering the water. It has long been known that salps are not selective feeders and that methods and mechanisms for feeding are similar in all species thus far studied (see Ihle, 1935, 1937–39).

In order, then, to attempt a segregation of the niches of the various species of salps, an analysis of the gut contents of all species reported here was undertaken, and observations were made as to their probable predators. Various salp species were chosen from different latitudes, longitudes, and cruises in order to have a respresentative sample. This resulted in the following observations: the food of all specimens and species of salps is remarkably similar throughout the area studied; and the food of all salp species within any one plankton sample is the same.

SUMMARY OF THE RESULTS OF THE GUT CONTENT ANALYSES

very common food	unidentified matter
	diatoms
	dinoflagellates
common food	silicoflagellates
	radiolarians
	coccolithophores
	foraminiferans
rare food	small crustaceans (chiefly copepods)
	gastropod larvae
	pteropods
	annelids
	fish eggs

Enemies of salps under natural conditions are unknown. Observations that may provide a clue on this situation, however, have been made in the plankton samples. There is a certain amount of conjecture in such deductions because carnivorous animals can be expected to bite whatever is near them during the death struggle after formalin is added to a plankton sample. Nevertheless, animals that contain salps in their digestive tracts or that hold to salps in the preservative may be their enemies in nature. Obviously, a chaetognath could be predaceous on *Thalia democratica* but not on *Thetys vagina* except in its young stage. The following animal types have been observed holding onto salps in preserved plankton tows: chaetognaths, heteropods, coelenterates, and crustacea (chiefly copepods and hyperiid amphipods). No planktonic animals have been observed to contain salps in their guts, but special study was not performed with this object in mind. Thompson (1948: 160) reported *Salpa fusiformis* from stomachs of blue cod from New Zealand, and Reintjes and King (1953) reported *Pyrosoma* sp., unidentified salps, and unidentified tunicates other than these in the gut contents of yellowfin tuna (*Neothunnus macropterus*). Fraser (1949) reported *I. asymmetrica* (= *I. punctata*) and *Dolioletta gegenbauri* from a herring stomach, and that salps were reported as part of the

food of the pelagic turtle, *Thalassochelys caretta*. I have recently identified five specimens of *Thalia democratica* agg. from the gut contents of a fish, *Chaetodon unimaculata*, taken by rotenone poison off Honolulu at a depth of about 25 feet. This fish contained many appendicularians also, probably of the genus *Oikopleura*. Other than this, no information is available as to the enemies of salps.

Because there is no apparent selection of food, and because the food, feeding methods, and mechanisms are similar in all species of salps, and because enemies are evidently similar, all salp species appear to occupy similar niches (with some slight differences between salps of different sizes in their ability to handle the larger food organisms). Inasmuch as many species of salps have been found together in one plankton tow (up to 9 in the POFI collections studied), and all species in a plankton tow can be assumed to be subject to at least approximately the same enemies and to the same environmental conditions, it can be stated that all salps apparently occupy similar niches simultaneously, and are, for all practical purposes, ecological equivalents. This statement doubtless applies to many other plankters as well as to salps: Any one niche in the plankton community of the epipelagic zone of tropic oceanic waters may be occupied simultaneously by many species. To illustrate, a few specimens of doliolids and pyrosomids have been subjected to a gut content analysis, and these animals also contained generally the same food organisms as the salps. Appendicularians, although to some extent feeding on similar food as other planktonic tunicates, are probably more restricted in the type of food they can handle as a result of their highly modified food-catching mechanisms, and are thus probably limited in their equivalence with other pelagic tunicates. It is probable that predaceous plankters such as chaetognaths, heteropods, coelenterates, and some crustacea found in tropic epipelagic waters also occupy similar niches simultaneously.

Marshall and Orr (1953) briefly discussed the concept of the niche (including the concept of habitat in the same term) in regard to the plankton community and pointed out that ". . . it is at first sight hard to understand how different ecological niches can be available in a medium so constant as sea water." They suggested that differences in niches among plankters may be found in the different foods on which the plankters depend. Such a suggestion may be applicable to plankters found in coastal and temperate waters, but for tropic oceanic waters it seems scarcely applicable, at least to the salps and undoubtedly also to many other plankton animals. To be certain of this niche equivalence, it would be desirable to know the vertical distribution of the captured animals, but the tows studied cannot furnish such information, as they were made with an open net. Conjectures have been made as to the causes and results of this apparent niche equivalence of many species, but they are not included in this report. They have resulted in a study of species variety in Silver Springs, Florida, in which factors controlling the numbers of species are discussed (Yount, 1956).

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Some Trematodes of Fishes from the Central Equatorial Pacific

Edwin S. Iversen[1] and Earl E. Hoven[2]

This report is based on a collection of trematodes from marine fishes captured in the vicinity of the Line Islands. All the trematode species listed are believed to constitute first records from this area, and some are first reports from new hosts. Collections were made in 1955 during exploratory tuna fishing by trolling and longlining. These fishing surveys were carried out by Pacific Oceanic Fishery Investigations (POFI), a branch of the U. S. Fish and Wildlife Service, as one phase of a program designed to determine the distribution and abundance of tunas in the Pacific. The Line Islands from which this material was collected are: Christmas, Fanning, Washington, and Palmyra islands, and Kingman Reef. They extend in a northwesterly direction from 2° N. latitude, 157° W. longitude to 6° N. latitude, 163° W. longitude.

All specimens, except the hemiurids, were identified through the kind efforts of Dr. Harold W. Manter, Department of Zoology, University of Nebraska. Unfortunately facilities were not available aboard ship for proper preservation of such material; as a result many of the specimens were identified with difficulty and some could not be accurately identified. Dr. Donald C. Matthews, Department of Zoology, University of Hawaii, very kindly provided sections of the encysted didymocystid included herein. Thanks are extended to E. Dixon Stroup, POFI, for making the photographs used in this report. All collections have been deposited in the U. S. National Museum.

Order MONOGENEA

Family MICROCOTYLIDAE

Neothoracocotyle acanthocybii
(Meserve, 1938)

SYNONYMS: *Gotocotyla acanthocybii* Meserve, 1938.

HOST: Wahoo, *Acanthocybium solandri* (Cuvier and Valenciennes).

LOCATION: Between gill filaments.

LOCALITY: Kingman Reef, 6° 20' N., 162° 30' W.

SPECIMENS: USNM Helm. Coll. No. 38132.

PREVIOUSLY REPORTED HOSTS AND LOCALITIES: *Acanthocybium solandri* from the Galapagos Islands.

DISCUSSION: Since these parasites are located between the gill filaments, they are found only by rather close scrutiny. Other duties while at sea prevented a careful record of the number of infected fish. The number of worms per host is probably large and the rate of infestation high. Hargis (1956), who has erected the genus *Neothoracocotyle*, reported the new combination.

Family CAPSALIDAE

Capsala poeyi (Vigueras, 1935) Price, 1938

SYNONYMS: *Tristomum poeyi* Vigueras, 1935.

HOST: Black marlin, *Makaira ampla*[3] (Poey).

LOCATION: Outside surface on isthmus and second dorsal fin.

LOCALITY: 04° 48' N., 160° 37' W. (vicinity of Washington Island).

[3] Identification of the Pacific *M. ampla* was based on an unpublished key provided by Dr. William F. Royce. As this paper goes to press, it is apparent that there is considerable disagreement concerning the classification of the marlins.

SPECIMENS: USNM Helm. Coll. No. 38131.

PREVIOUSLY REPORTED HOSTS AND LOCALITIES: Reported from the same species of host off Havana, Cuba, by Vigueras (1935).

Capsala biparasitica (Goto, 1894)
Price, 1938

SYNONYMS: *Tristoma biparasitica* Goto, 1894.

HOST: Yellowfin tuna, *Neothunnus macropterus* (Temminck and Schlegel).

LOCATION: Firmly attached to carapace of copepods found in gills.

LOCALITY: 02° 14′ N., 159° 59′ W. (vicinity of Christmas Island).

SPECIMENS: USNM Helm. Coll. No. 38134.

PREVIOUSLY REPORTED HOSTS AND LOCALITIES: Goto collected this species of trematode from a copepod (*Parapetalus* sp.) on *Thynnus albacora* from Misaki, Japan.

DISCUSSION: The copepod involved in the present record is *Elytrophora* sp. A comparison of these host records is of particular interest because the trematode is a hyperparasite and because in each collection both the copepod hosts are caligid copepods and the fish hosts are closely related.

Family HEXASTOMATIDAE

Hexostoma grossum (Goto, 1894)
Sproston, 1946

SYNONYMS: *Hexacotyle grossa* Goto, 1894.

HOST: Bigeye tuna, *Parathunnus sibi* (Temminck and Schlegel).

LOCATION: On gills.

LOCALITY: 02° 45′ N., 158° 05′ W.

SPECIMENS: USNM Helm. Coll. No. 38133.

PREVIOUSLY REPORTED HOSTS AND LOCALITIES: On gills of *Thynnus* sp. from Misaki, Japan (Goto, 1894); type host corrected to *Parathunnus sibi* and reported on gills of *Katsuwonus vagans* and *Thunnus orientalis*, and on *Seriola quinqueradiata* from Japan (Ishii and Sawada, 1938).

Order DIGENEA

Family HEMIURIDAE

Hirudinella marina Garcin, 1730

SYNONYMS: Nigrelli and Stunkard (1947) include a very lengthy list of possible synonyms of this species.

HOST: Yellowfin tuna, *Neothunnus macropterus* (Temminck and Schlegel).

LOCATION: In stomach.

LOCALITY: 06° 20′ N., 162° 30′ W. (vicinity of Kingman Reef).

PREVIOUSLY REPORTED HOSTS AND LOCALITIES: Nigrelli and Stunkard (1947) include a long list of hosts, mostly of scombriform fishes, including *N. macropterus* from C. San Lucas, Lower California, Pacific.

DISCUSSION: In the course of the examination of stomach contents of yellowfin and bigeye tuna from the central Pacific, King and Ikehara (1956) encountered large muscular trematodes. They report an infection rate of 32 per cent for 166 bigeye and 26 per cent for the 439 yellowfin they examined. Since Nigrelli and Stunkard recognize only two species of *Hirudinella*, one in the wahoo, *H. ventricosa*, and one in other hosts, *H. marina*, it is very likely that these worms belong to the latter species.

Hirudinella ventricosa Pallas, 1774

SYNONYMS: Nigrelli and Stunkard (1947) list nine possible synonyms.

HOST: Wahoo, *Acanthocybium solandri* (Cuvier and Valenciennes).

LOCATION: Stomach.

LOCALITY: Christmas, Fanning, Washington, Palmyra islands, and Kingman Reef.

PREVIOUSLY REPORTED HOSTS AND LOCALITIES: *Acanthocybium solandri* in the Atlantic and Pacific; from the Pacific it has been reported from Panama, Mexico, Equador, and the Marianas Islands (Nigrelli and Stunkard, 1947).

DISCUSSION: Nigrelli and Stunkard (1947) have made a thorough study of this genus and

regard all *Hirudinella* reported from the wahoo as belonging to a single species, *H. ventricosa* Pallas. In an examination of 220 wahoo stomachs from the Line Islands, Iversen and Yoshida (1957) found a 98.2 per cent infection of these parasites. The hosts ranged in size from 108 to 172 cm. and as many as 17 of the worms were found in a single stomach, with 2 per host occurring most frequently.

H. ventricosa may be present elsewhere in the Pacific, for Edmondson (1946) states in respect to the Hawaiian region, that "An undetermined species of trematode commonly occurs in the stomach of the Ono, *Acanthocybium solandri* (Cuvier)." These flukes were about 1 inch long when partially contracted. Kishinouye (1923) in speaking of wahoo from Japan says "A large distomum, about 8 cm. in length, is almost always found in the stomach."

Family DIDYMOZOONIDAE

Didymocystis acanthocybii
Yamaguti, 1938

HOST: Wahoo, *Acanthocybium solandri* (Cuvier and Valenciennes).

LOCATION: Base of gill arches and on operculum.

LOCALITY: Christmas, Fanning, Washington, Palmyra islands, and Kingman Reef.

SPECIMENS: USNM Helm. Coll. No. 38171.

PREVIOUSLY REPORTED HOSTS AND LOCALITIES: At base of gill arch of *Acanthocybium sara* (Lay et Bennett); Pacific, Japan, Yamaguti (1938).

DISCUSSION: Of the 104 wahoo examined, 53 revealed conspicuous cysts of this parasite (Fig. 1). The fish ranged in size from 86 to 174 cm., and specimens of all sizes within this range were found to be infected. Figure 2 shows the relationship of the paired worms within the cyst.

Didymocystis sp.

HOST: Yellowfin tuna, *Neothunnus macrop-*
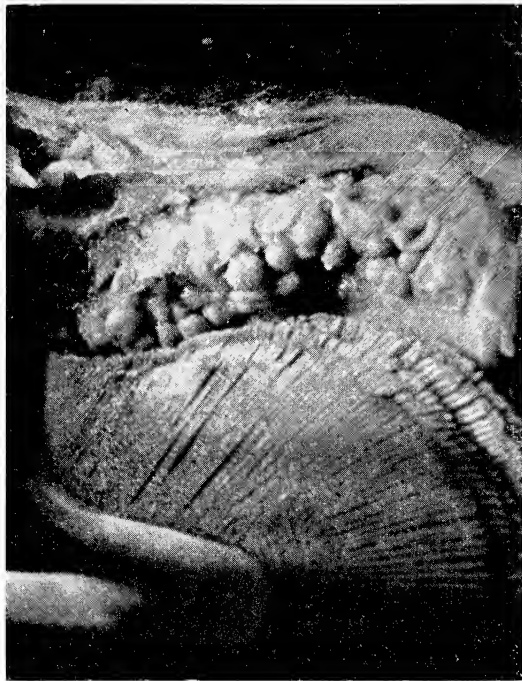
FIG. 1. Photograph of encysted *Didymocystis acanthocybii* on the side of the head of a wahoo (gill cover removed).

terus (Temminck and Schlegel).

LOCATION: On gill filaments.

LOCALITY: 00° 28′ N., 157° 48′ W.

SPECIMENS: USNM Helm. Coll. No. 38172.

DISCUSSION: The condition of specimens does not permit identification, but they resemble *D. wedli* Ariola, 1902, more closely than others. The infection rate of yellowfin is probably not high.

DISCUSSION

Concomitant studies of hosts and parasites from different geographic areas have been reviewed by Metcalf (1929) and Manter (1955), who have presented considerable evidence that parasites reflect the distribution and way of living of their hosts. A basic problem in the study of some pelagic fishes is to determine whether the population of each important species is continuous throughout its range or whether it is composed of a number of independent or semi-independent

units. In this connection these records, especially of Monogenea which are host specific, are of interest. *Capsala biparasitica* from yellowfin tuna in Japan and the Line Islands, *Hexastoma grossum* from bigeye in Japan and the Line Islands, *Neothoracocotyle acanthocybii* from wahoo in the Line and Galapagos islands, and *Capsala poeyi* from the black marlin in the Atlantic and Pacific, all suggest that these stocks of fish are not, or were not, completely independent.
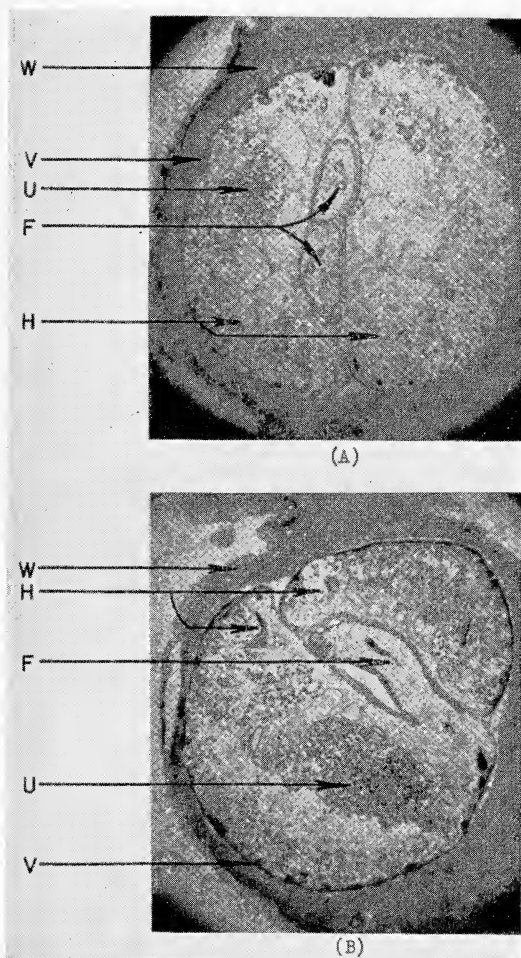

FIG. 2. *Didymocystis acanthocybii.* (A) Photomicrograph of a cross section through two trematodes showing the host tissue (W) surrounding the cyst, the forebodies (F), the hindbodies (H), the uterus (U), and vitellarium (V) of each. (B) Photomicrograph of a section through two trematodes showing the forebody of one in sagittal section. 10 microns.

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Two New Doliolids from the Eastern Pacific Ocean[1]

Takasi Tokioka[2] and Loe Berner[3]

THE MATERIAL upon which this report is based was collected during the Shellback Expedition carried out by Scripps Institution of Oceanography in 1952. This expedition conducted its work in the east central Pacific Ocean off Central America and northern South America. While the authors were examining the many plankton samples they found two unusual doliolids. These specimens were from samples taken in the waters off Peru. The specimens are all gonozooids; and although they are not in a good state of preservation, the arrangements of muscles, alimentary organs, and gonads have been determined by close examination, after staining with Rose Bengal. One of the two forms belongs to the genus *Doliopsoides* established by Krüger (1939: 138–139). This genus, in the appearance of the musculature, shows an intermediate state between the Cylomyaria and the Desmomyaria. The other form belongs to the genus *Doliolina*. Both forms differ from any previously described species known to us and we consider them to be new species.

This is the first reported occurrence of the genus *Doliopsoides* from the Pacific Ocean and, indeed, is the first report of the genus since it was described by Krüger. At present the known distributions of *D. horizoni* and of *D. undulatum* are limited to only two stations.

Doliopsoides horizoni new species
Fig. 1

Three gonozooids are dealt with here. All were found in the sample from station SB-115 located at 8° 16′ S., 83° 42′ W. They are 3.9 mm., 4.6 mm., and 5.2 mm. in length. One additional specimen was taken at station SB-118 located at 9° 49′ S., 83° 02.5′ W. The body is roughly barrel-shaped with the oral aperture at the anterior end and the atrial aperture at the posterior end of the body. Both apertures are rather wide and fringed with a narrow margin which is, apparently, without lappets. The test is of moderate thickness, very soft, and easily stripped from the body. The mantle is extremely thin and delicate. The muscles are rather narrow, especially I, VII, and VIII. Muscles I through IV and VIII form complete hoops. The first and seventh intermuscular zones are narrow while the second is quite wide. Muscle V runs obliquely from the posteroventral to the anterodorsal side and is widely interrupted at the middorsal line. Each dorsal end of muscle V turns backwards for a short distance and then runs obliquely to the posteroventral side. These parts represent muscle VI and are arranged parallel to muscle V. They are not continuous across the mid-ventral line. There is a short section on each of the ventral ends of muscle VI which turns slightly forward. Each of the ventral ends of muscle VII passes external to muscle VI on the side of the body. Muscle VII ends slightly below the mid-ventral line, just after crossing muscle VI. In addition to these muscles there are two narrow, short connecting muscles (lateral longitudinal muscle, l.l.m.) between muscles IV
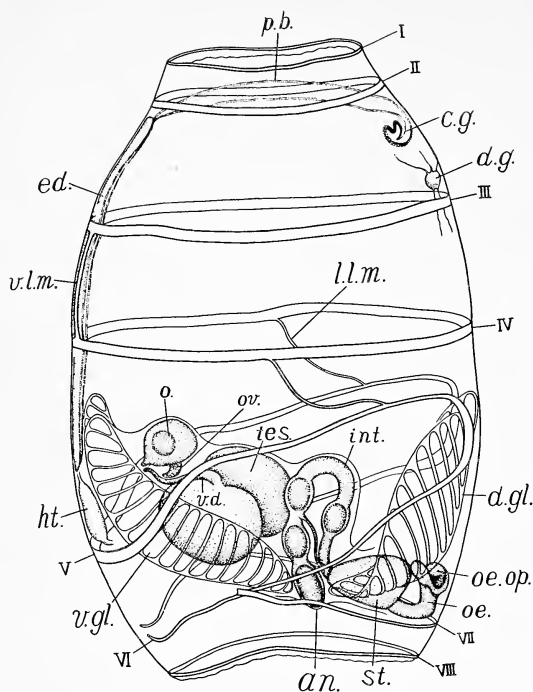
FIG. 1. *Doliopsoides horizoni* n. sp., gonozooid from left side. I–VIII, circular body muscles; *an.*, anus; *c.g.*, ciliated groove; *d.g.*, dorsal ganglion; *d.gl.*, dorsal gill; *ed.*, endostyle; *ht.*, heart; *int.*, intestine; *l.l.m.*, lateral longitudinal muscle; *o.*, mature ovum; *oe.*, oesophagus; *oe.op.*, oesophageal opening; *ov.*, ovary; *p.b.*, peripharyngeal band; *st.*, stomach; *tes.*, testis; *v. d.*, vas deferens; *v.gl.*, ventral gill; *v.l.m.*, ventral longitudinal muscle.

and V, one on each side of the body. These muscles extend from just below the midlateral portion of muscle IV obliquely upward, joining muscle V just above the midlateral line. Another narrow longitudinal muscle (ventral longitudinal muscle, v.l.m.) connects muscles III and IV along the midventral line.

The endostyle (ed.) is long and rather thick although its consistency does not seem to be compact. Anteriorly it begins just behind muscle II and extends posteriorly to slightly beyond the middle of the fourth intermuscular zone. The anterior margins of the peripharyngeal bands (p.b.) project slightly in front of muscle II. The ciliated groove (c.g.) is located near the middle of the second inter-

muscular zone, the dorsal ganglion (d.g.) is in the same zone near muscle III. The gill consists of a dorsal (d.gl.) and a ventral pair (v.gl.) of lamellae. It extends dorsally to the level of the ends of muscle V and ventrally to the middle of the fourth intermuscular zone or slightly anterior to it. The dorsal and ventral lamellae approach just above the juncture of muscle VI and VII. The gill bears in all 30 to 40 elongate stigmata.

The oesophageal opening (oe.op.) is located on the dorsomedian line near muscle VII, the oesophagus (oe.) itself is strongly curved. The stomach (st.) is situated vertically and in outline roughly forms an elongate triangle with the pyloric portion the narrowest. The intestine (int.) forms a **U**-shaped loop in the saggital plane of the body which ends with the anus (an.) near the pyloric end of the stomach. The proximal portion of the loop is somewhat thinner than the other portions and it is not certain whether this represents a hind stomach. The formation of fecal pellets was observed in all three specimens. Krüger in his description of *D. meteori* mentioned the formation of "Kotballen" in the intestine. There is a thin but distinct vessel connecting the pyloric portion of the stomach with the middle of the ventral branch of the intestinal loop. The ovary (ov.) is situated just dorsal to the posterior end of the endostyle and slightly to the right of the median line. In one specimen the ovary contains a large mature ovum (o.). The oviduct is so short as to be practically absent. The testis (tes.) is located between the ovary and the intestinal loop. It consists of two spherical lobes. The vas deferens (v.d.) is short but distinct, and extends from the testicular lobes to near the ovary, probably in the region of the female genital pore. The heart (ht.) lies between the posterior end of the endostyle and muscle V.

REMARKS

This form is evidently very closely related to *Doliopsoides meteori* (Krüger, 1939). Krüger's genus and species were described from a

plankton sample taken at Meteor station 267, in the layer between 400 and 200 meters, in the Atlantic Ocean off Cape Verde. Our specimens differ distinctly from Krüger's species in the following points: (1) The ventral longitudinal muscle connects muscles III and IV rather than muscles II and III as in *D. meteori*. (2) The oesophageal opening is situated on the middorsal line just anterior to muscle VII while in *D. meteori* it is located centrally on the level with muscle VI (see Krüger's fig. 87). (3) Muscle VI is interrupted at the midventral line in *D. horizoni* while it is continuous in *D. meteori*. In one part of Krüger's text figure the ventral ends of muscle VII are shown as if they passed internally to muscle VI, in another as if they passed externally to muscle VI. This apparent error may have been due to the poor condition of his specimens, but makes it impossible to compare the two species on this point. The specific name *horizoni* refers to the vessel which carried the Shellback Expedition; this follows Krüger's lead in naming his species after the ship from which it was taken. Comparing the structures of *D. meteori* and *D. horizoni* we have come to the conclusion that the genus *Doliopsoides* may be defined as follows:

Doliopsoides Krüger 1939: oozooid, trophozooid, and phorozooid unknown.

Gonozooid: The gonozooid is barrel-shaped with eight nearly hooplike muscles. Muscles I through IV and VIII form complete hoops while V, VI, and VII are interrupted. In addition to the circular muscles there are some longitudinal muscles, which are variously placed on the body. Both the ciliated groove and the dorsal ganglion are situated in the second intermuscular zone. The gill consists of a dorsal and a ventral pair of lamellae. The gonads are located anteroventrally to the alimentary organs. Although there are some rather marked differences between our specimens and Krüger's description we do not feel they warrant more than specific treatment. The type species is *Doliopsoides meteori* Krüger 1939.
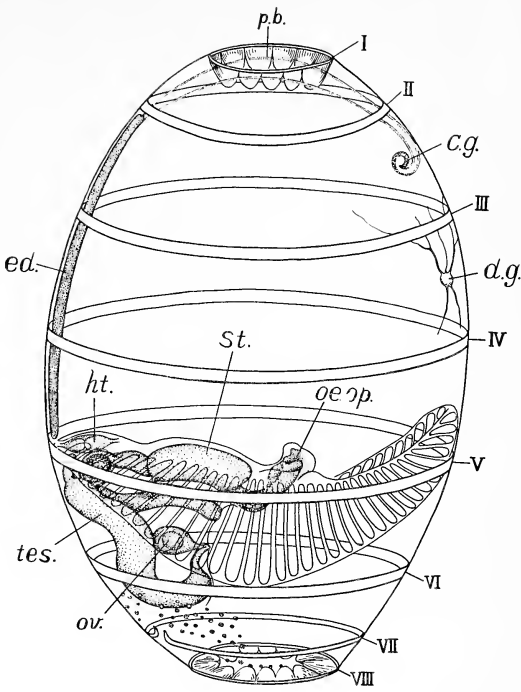

FIG. 2. *Doliolina undulatum* n. sp., gonozooid from left side. For abbreviations see Figure 1.

Doliolina undulatum new species
Fig. 2

This species is represented by five gonozooids from station SB-115 and four gonozooids from station SB-94. The location of SB-115 is given above, SB-94 was located at 9° 58.5′ S. and 95° 01′ W. These latter specimens are in a very poor state of preservation and we will deal here only with those from SB-115. They range from 3.3 to 4.6 mm. in length. The test is of moderate thickness but very soft and easily stripped from the body. The general appearance of the body and the arrangement of the eight circular muscles is quite similar to *D. intermedium* (Neumann, 1906), which occurs frequently in the Shellback area. A most striking difference is the interruption of muscle VII at the mid-ventral line in this new species. The mantle is thin. The muscles are narrow, especially I and VIII. Muscle VII is also somewhat narrower than the rest.

The endostyle (ed.) is very long, extending anteriorly nearly to muscle II and posteriorly to the anterior margin of muscle V. The anterior margin of the peripharyngeal band (p.b.) extends forward almost to muscle I. The ciliated groove (c.g.) is situated near the middle of the second intermuscular zone. The dorsal ganglion is situated in the third intermuscular zone, its posterior edge is at the middle of the zone. The gill septum extends from the middle of the fourth intermuscular zone dorsally, obliquely back to the level of muscle VI and then obliquely forward to the level of muscle V ventrally. It bears 30–40 pairs of elongate stigmata.

The oesophageal opening (oe.op.) is located approximately on the longitudinal axis near the posterior margin of muscle V. The stomach (st.) is located vertically at the same level; it is roughly rectangular in outline, slightly curved with the convex side forward. The intestine forms a simple loop and ends with the anal opening near the cardiac portion of the stomach and on a level with the middle of the fifth intermuscular zone. The hind stomach and mid-intestine are rather distinctly marked. There appears to be a thin short vessel connecting the pyloric end of the stomach with the middle of the posterior branch of the intestinal loop.

The ovary (ov.) is situated on a level with muscle VI, slightly to the right of the mid-ventral line. The testis (tes.) is somewhat sausage-shaped. It extends, with an undulating course, along the left side of the body between muscle V and the genital pore. There are a number of small cell groups scattered over the ventral half of the sixth intermuscular zone and on a small portion of the seventh intermuscular zone.

REMARKS

The oozooid, trophozooid, and the phorozooid of this species are unknown.

Gonozooid: At a glance the present new species may be confused with *D. intermedium* (Neumann, 1905: 211). The longer endostyle in *D. undulatum* can be used as a good indicator to distinguish it from *D. intermedium*. In most of the specimens of *D. intermedium* collected in the Shellback area the endostyle reaches only slightly beyond the middle of the second intermuscular zone and its posterior end is located near the middle of the fourth intermuscular zone. The mid-ventral interruption of muscle VII is also unique in *D. undulatum*. *Dolioletta mirabilis* is the only doliolid, outside the genus *Doliopsoides*, which has an interrupted muscle band. In this case there is a mid-ventral interruption of muscle VI below the gut. The characteristic appearance of the testis, from which the specific name of the new species has come, is also unique and serves to separate the species from all others in the genus.

The following material, upon which part of the descriptions herein are based, has been deposited in the U. S. National Museum:

1. *Doliopsoides horizoni*, gonozooids, SYNTYPES, 3 specimens USNM Cat. No. 11368. These specimens were poorly preserved and it was felt impossible to designate a type from among them. They are all from station SB-115.

2. *Doliolina undulatum*, gonozooid, HOLOTYPE, 1 specimen USNM Cat. No. 11369.

3. *Doliolina undulatum*, gonozooids, PARATYPES, 4 specimens USNM Cat. No. 11370.

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A New *Hedyotis* from Kauai, Hawaiian Islands

Benjamin C. Stone and Irwin Lane[1]

THE MOST RECENT revision of the Hawaiian species of *Hedyotis* (Rubiaceae) is that of F. R. Fosberg (1943), who treated all the Polynesian species, describing many new forms. The genus as considered by Fosberg includes, with good reason, the segregate genera *Oldenlandia* L., *Gerontogea* Cham. and Schlecht., *Kadua* Cham. and Schlecht., *Diplophragma* Meisn., as well as *Gouldia romanzoffiensis* A. Gray, a species not properly in *Gouldia*.

The type species of *Hedyotis* is *H. auricularia* L., which forms also the basis of the subgenus *Hedyotis*. This subgenus contains the species native to southern Asia which have axillary inflorescences, indehiscent or septicidal fruits, and usually a depressed habit of spermacoccoid appearance. The sections and subgenera found in Polynesia are as follows.

Subgenera: *Oldenlandia*, including only *Hedyotis biflora* L., a wide-spread plant of tropical Asia, the islands of the Indian Ocean, Malaysia, Micronesia, Melanesia, Fiji, and, in Polynesia, Samoa and Tonga.

Diplophragma, of southern and western Polynesia, eastern Melanesia, and Micronesia, but not known from Hawaii.

Kadua, two variable species confined to the Hawaiian Islands.

Oceanica, comprising the single species transferred from *Gouldia*, and present only in southern and central Polynesia.

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Polynesiotis, with 19 species, principally developed in Hawaii, with a secondary center in southern Polynesia. This subgenus has five sections: *Wiegmannia*, *Protokadua*, *Gouldiopsis*, *Bikkiocarpa*, and *Austrogouldia*.

The new species described herein fits well into the subgenus *Polynesiotis* and into the section *Wiegmannia*. However, it differs in two of the key characters employed in Fosberg's key to the subgenera. First, in our specimens the stigmas are consistently quadrifid, not bifid; second, the width of the corolla tube is not "much less than ⅓ the length" of the corolla tube, as the key states, but is in some cases as wide as it is long. At first glance the inflorescences seem axillary, but on closer inspection it can be seen that they are strictly terminal; however, the first axillary bud below the inflorescence grows into a stem (or in some cases both of the two axillary buds), and these in turn eventually terminate in inflorescences; this gives the plants an aspect of branching which might be termed subscorpioid.

Within the section *Wiegmannia* of the subgenus *Polynesiotis*, our specimens are evidently very closely related to *Hedyotis littoralis* (Hbd.) Fosberg, a striking and characteristic species distinguished by its fleshy leaves, which are closely set on a decumbent corky stem, and by its habitat on cliffs or rocks close to the sea. It is known mostly from Molokai and Maui; although there exist specimens from Kauai, Oahu, and Hawaii, they are old (Hillebrand's from Kauai and Oahu, Abbé Faurie's

from Hawaii), and there have been apparently no other collections in these localities since the original specimens were taken. Fosberg says "the plant has become quite rare, except on the windward coast of east Molokai. I searched for it without avail at Hanalei, Kauai, in 1935. It has not been found on Oahu since Hillebrand's time."

Our specimens exhibit many features characteristic of *H. littoralis*, including its habitat preference, but in flower color, corolla shape, and fruit shape they show clear-cut differences. The general aspect of both species is very similar, and the two are both quite different in this regard from the majority of the other Hawaiian species of *Hedyotis*.

The following changes in the keys should be made to accomodate this new species. In the key to the subgenera (Fosberg, 1943: 19), under the second number 2, read: "Corolla fleshy or at least thickened, salverform, anthers included or the tips barely exserted, style shorter than or subequal with tube, bifid or quadrifid (lobes may cohere), seeds angular......3." Under the second 3, read: "Inflorescence terminal, terminal and axillary, or seemingly axillary but terminating the main stem, the branch below arising from the first axillary bud(s)......4." Under the second 4, read: "Width of corolla tube usually much less than ⅓ the length, but in some as wide as long; cyme usually many-flowered; fruit dry, or if fleshy, calyx lobes much over 1 mm. long......*Polynesiotis*."

In the key to the sections of *Polynesiotis* (Fosberg 1943: 23), under the first 2, read: "Calyx lobes foliaceous, longer than hypanthium in flower, conspicuously accrescent in fruit, distinctly nerved, subscabrous in some; corolla limb not quadrangular in bud, inflorescence usually quite glaucous.........*Wiegmannia*."

In the key to the species of section *Wiegmannia*, insert in place of the lead to *H. littoralis*: "2. Leaves, bracts, calyx lobes, and ovary fleshy; leaves mainly sub-basal......3.

3. Corollas white, the tube two or three times longer than wide; fruits subglobose, crowned by the persistent enlarged calyx ....**H. littoralis**

3. Corollas green, the tube as long as wide or up to twice as long as wide; fruits usually conspicuously flattened, the persistent enlarged calyx lobes spreading from the equatorial plane of the fruits... ....**H. St.-Johnii**"

DESCRIPTION

Hedyotis St.-Johnii B. C. Stone and I. Lane sp. nov. (Subgen. POLYNESIOTIS sect. WIEGMANNIA)

Suffrutex parvus non- vel pauci-ramosus decumbens in scopuloris saxatilis maritimis Kauaiensibus habitans, caulis lignosus longitudinaliter sulcatus, petiolis connatis et fasciis suberosis inter foliosis ambis cinctis, folia opposita dense conferta irregulariter elliptico-acuminata ad apicem saepe asymetrice curvata in vivo subcarnosa convexa supra fusco-viridia et nitida infra subglauca pullovenosa, bases foliorum lati-petiolatae vel alatae bases bini connatae, laminae 5–14 cm. longae 2–5.5 cm. latae marginibus integribus, superficies foliorum (et bracteorum et calicorum) minute albo-scabratus, costa nervique leviter prominulentes, nervi laterales 4–10 arcuatim adscendentes vix anastomosantes (rete venularum conspicuum sed minutum), folia emortui persistentes vestirentes, inflorescentia stricte terminalis pauci-ramosa usque 17 cm. longa remote bracteata thyrsoidea tripartite cymosa, ramus quisque dichasius fere

FIG. 1. A–F, *Hedyotis littoralis*. A-1, Faurie 374, Molokai; 1, calyces, 1*a*, fruit; 2, Faurie 375, Halawa, Hawaii, fruits. B, Skottsberg 800, East Maui, 250 m. alt.; 1, calyx, young; 1*a*, fruit. C, Degener and Nitta 9430, Wailau, Molokai; 1, bud; 1*a*, fruit. D, same, 2d sheet; 1, buds and young calyces; 1*a*, fruit. E, Forbes 237-M, Keaneae, East Maui; 1, flower; 1*a*, fruits. F, leaves, 1, 2, Rock 7003, Wailau, Molokai; 3, Faurie 374; 4, Fosberg 13451, Wailau, Molokai; 5, Forbes 237-M; 6, Skottsberg 800; 7, Degener and Nitta 9430, sheet 2. (All in Bishop Mus.) All natural size.
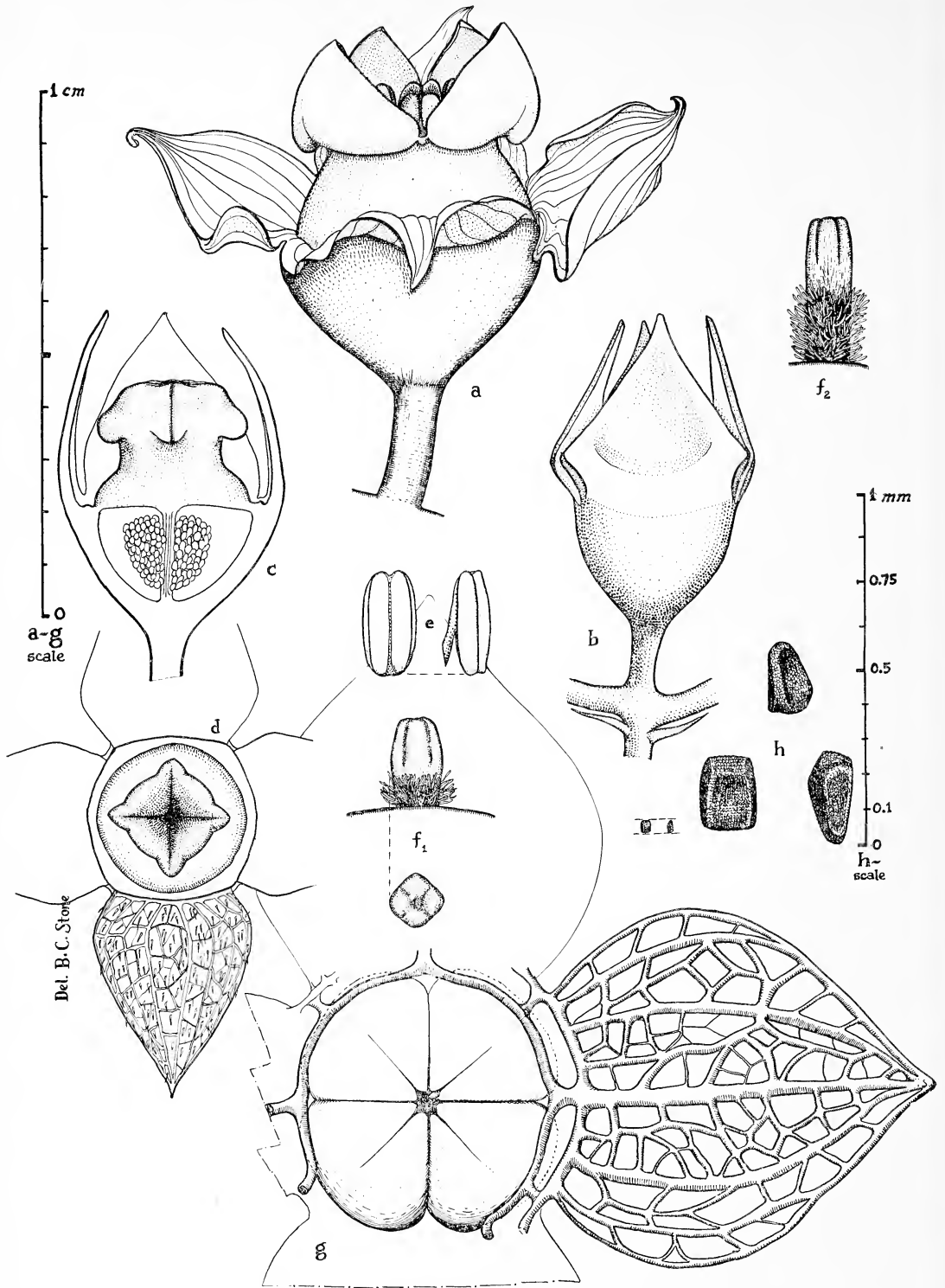
FIG. 2. *Hedyotis St.-Johnii.* a, Young flower; b, bud showing calyx; c, cross-section of bud, showing young corolla; d, top view of bud with calyx lobes spread; e, anther, front and side; f₁, young pistil; f₂, older pistil; g, fruit, top view, showing calyx expansion and dehiscence lines; h, seeds. All × 7½.
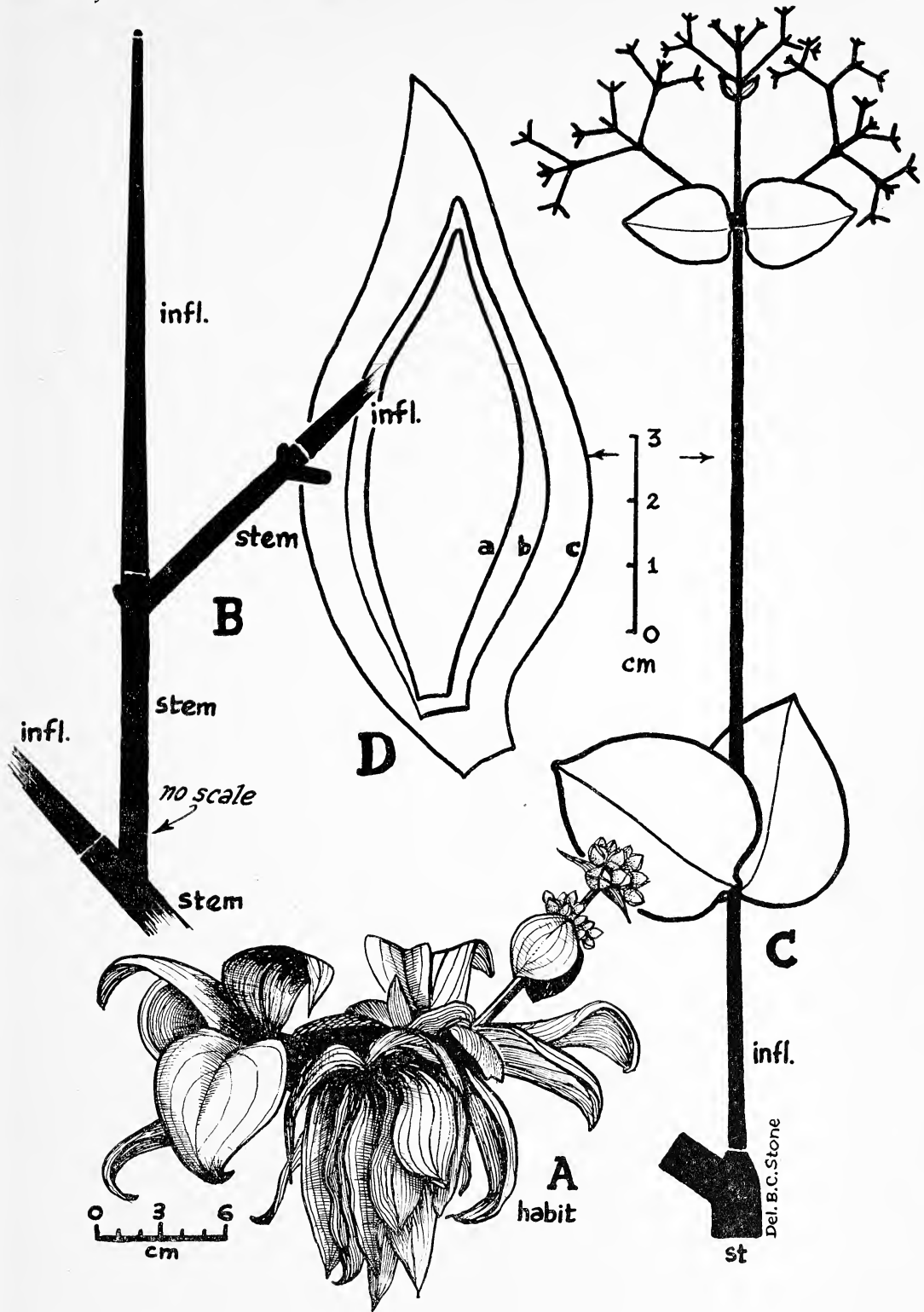
FIG. 3. A, *Hedyotis St.-Johnii,* habit sketch, (from Kodachrome by B. C. Stone); B, stem, branching pattern, showing terminal inflorescences; C, inflorescence; D, representative leaves. A- × ⅓; B-D, × 1.

11 floris ferrens, flos omnis bracteolo unico subulato fere 1 mm. longo subtentus, bracteae 2 rare 4–6 ovatae vel subcordatae ad apicem acutae vel subacuminatae 1–3 cm. longae 1.3–2.1 cm. latae inferiores longiores, flos junior subcuboideus, flos vetustior urceolatus 8–11 mm. diam., pedicellus 2 mm. longus, calyx in alabastro valvatus 4-lobatus, lobi calycis hastati subrhomboidali 4–6 mm. longi quam corollam longiori, corolla in alabastro ad apicem depressa 5–8 mm. longa lobi in flore leviter divergentes 1.5–2.5 mm. longi viridi, stamina subsessilia cum corolla adnata vix exserta, antherae 1.5 mm. $\times$ 0.8 mm., pistil 1, ovarium inferius, hypanthio discoideo, stylus ca. 3 mm. longus in basi pubescenti ad apicem quadrifidem, fructus siccus lentiformis vel subglobosus calyx persistens accrescens ad mediam fructus cinctus, fructus 4-locularis dehiscens primo loculicidalis illo tempore septicidalis, maturitas 4–6 mm. diam., semina angulosa nigra 0.2 mm. longa.

Ab. *H. littoralio* corolla brevioribus urceolati viridi (non albi) et fructu lentiformi differt.

Suffrutescent, decumbent, sparsely branching plants growing on rocky cliffs near the sea (known only from near Kalalau, Kauai), with woody stems up to 30 cm. long covered by a corky, longitudinally grooved epidermis and banded by corky rings and the connate bases of the petioles, the stems usually hidden by the congested persistent opposite dead and living leaves, the branching pattern subscorpioid and the branches somewhat parallel, inflorescences terminating each branch and a new branch growing from the axillary bud just below the inflorescence (or sometimes both buds developing into branches), these branches in turn terminating in inflorescences, etc. The stems may reach a diameter of 1–2 cm. at the base, and are light brown to whitish in color. Leaves simple, entire, elliptical-acuminate with assymmetric curved apices, the length-width ratio rather variable, the petioles broad or alate and conspicuously connate, the blades 5–14 cm. long and 2–5.5

cm. wide, the surfaces minutely white-scabrous, the leaves when living rather fleshy, convex, dark shining green above and rather glaucous, but with darker veins, below; veins barely prominent, the 4–10 lateral nerves curving parallel, hardly anastomosing; the vein-reticulae apparent but delicate. Inflorescence terminal but seemingly axillary because of subscorpioid branching, the inflorescence up to 17 cm. long, a thyrsoid compound tripartite cyme, with each branch a strict dichasium of about 11 flowers, each flower subtended by a bracteole 1 mm. long, subulate in form; the dichasial branches average 1.5 cm. in length; the entire cluster of flowers may reach 2–3 cm. in width. Flowers in bud subcuboid, at anthesis urceolate, when mature 8–11 mm. in diameter; calyx glaucous green, glabrous except for minute white scabrae, in bud valvate, subcuboid, with four hastate subrhomboidal lobes whose basal corners are recurved-approximate, free; calyx longer than the corolla; the calyx-lobes in bud ca. 2 mm. long, in flower ca. 3 mm. long, in fruit ca. 8–10 mm. long; corolla green, in bud valvate, the four lobes inflexed at the top of the bud and forming a depression; in flower spreading or barely ascending, darker green within; corolla in bud 2–3 mm. long, in flower 5–8 mm. long, the lobes 1.5–2.5 mm. long, subtriangular, the neck constricted, the outer edges of the petals somewhat recurved or appearing ridged. Stamens 4, subsessile, adnate to the constricted neck of the corolla, the tips barely exserted, anthers 1.5 $\times$ 0.8 mm., the connective-filament 0.1–0.2 mm. long, anther-cells 4. Pistil 1, the ovary inferior, the hypanthium discoid, in flower not squared but becoming slightly so in fruit, 3–4 mm. wide in flower; style deeply quadrifid, the 4 lobes cohering; basal part of the style pubescent; lobes of the style 0.4 $\times$ 0.15 mm. Fruits dry, flattened-lentiform to depressed-subglobose, the calyx-lobes persisting-accrescent to about twice the size they are in flower, lobes fenestrate, 5–7+nerved, spreading, attached at the equator of the fruit; fruit

dehiscing first loculicidally across the disc, the pyrenes later separating by a septicidal slit. Seeds angular, blackish, papillose to granulate, small, ca. 0.2 mm. long.

HOLOTYPE: Hawaiian Islands, Kauai: Between Kalalau and Honopu, cliffs at end of beach; plants growing on rocky ledges and in crevices dashed by ocean spray, 10–30 ft. elevation, in association with *Artemisia australis* and *Lipochaeta succulenta*, December 24, 1956, Benjamin C. Stone no. 1470 (2 sheets, in Bishop Museum). (This locality is actually the same as the following.)

SPECIMENS EXAMINED: Hawaiian Islands, Kauai: Third gulch from east end of Honopu (Kalalau Trail), rare, in crevices of vertical basalt sea cliff, 10 ft. alt., herbaceous, leaves fleshy, above dark shiny green, below pale green with darker veins; infl. green, the buds cuboid, the calyx lobes valvate, within pale green, the corolla lobes valvate, within dark green, without pale green, assurgent; anthers exserted, yellow; December 31, 1947, Harold St. John, E. J. Britten, and R. S. Cowan no. 23,207 (2 sheets, in Bishop Museum).

DISCUSSION

Because of the close vegetative similarity of the species *Hedyotis littoralis* (Hillebrand) Fosberg and the newly described *H. St.-Johnii* Stone and Lane, there is the possibility that Hillebrand's collection from Hanalei, Kauai, might represent *H. St.-Johnii* rather than *H. littoralis*. Hillebrand (1888) added after the description of his *H. littoralis*, "On rocks near the seashore in Waikolu, Molokai! and Hanalei, Kauai! A single damaged corolla only was available for examination; the position of the anthers, shape of corolla lobes, and relative length of style remain therefore doubtful." Possibly also the color of the corolla in the Hanalei specimen was unknown. At any rate, until new and definite collections of *H. littoralis* are made on Kauai, it must remain a matter of doubt whether both of these species are actually present there. Since, however, the only two collections of *H. St.-Johnii* are from nearly the same locality along the Napali coast (Honopu and Kalalau are only about 3 miles apart, as the crow flies), and Hillebrand's specimen was from Hanalei, perhaps 15 miles away and in a less rugged and rocky area, the possibility still exists that this latter specimen represents *H. littoralis*.

Hedyotis St.-Johnii was first collected in 1947, by St. John, Britten, and Cowan, and was rediscovered in 1956, during a trip into the isolated and remote Kalalau Valley led by Harold St. John. About 10 plants were seen, at various heights from 10 to 30 feet up, on the vertical basalt faces of the cliffs at the west end of the beach between Kalalau Valley and Honopu Valley. Flowers and fruit seemed abundant, and the colony though small seemed healthy. The plants were continuously sprayed by a fine spume from the breaking waves. The only plant associates were *Artemisia australis* Less. and *Lipochaeta succulenta* DC., though other species were growing nearby at the base of the cliffs back of the beach.

ACKNOWLEDGEMENTS

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Revisionary Notes on the Phoxocephalidae (Amphipoda), with a Key to the Genera[1]

J. Laurens Barnard[2]

NOMENCLATURAL CHANGES deemed necessary by the writer are briefly discussed herein, including: (1) a new synonymy for the genus *Paraphoxus* Sars and a listing of useful specific criteria for that genus; (2) new combinations and new names in the genera *Paraphoxus*, *Heterophoxus* Shoemaker, and *Proharpinia* Schellenberg; (3) zoogeographical reasons for the provisional retention of the genus *Harpiniopsis* Stephensen; and (4) a new key to the existing genera of the Phoxocephalidae.

Initially, this study was a local faunistic problem in the marine basins off southern California (Hartman, 1955; J. L. Barnard, 1955). The wealth of materials collected in several hundred bottom samples by the research vessel, "Velero IV," necessitated an extensive review of phoxocephalid systematics in order to assign the many new species to appropriate genera. The present paper is confined only to a rearrangement of names and synonymies in the literature.

The writer wishes to acknowledge the help of the following persons for the loan of specimens and for advice: Dr. Olga Hartman, Hancock Foundation; Dr. Keith Sheard, C. S. I. R. O. Division of Fisheries, Western Australia, who examined Haswell's types for the writer through the courtesy of Dr. J. W.

Evans, director, The Australian Museum, Sydney; Dr. D. E. Hurley, New Zealand Oceanographic Institute; Dr. T. Soot-Ryen, director, Tromsø Museum; Dr. Karl Lang, Swedish State Museum of Natural History; Dr. Fenner A. Chace, Jr., and Dr. Thomas E. Bowman, U. S. National Museum; and Prof. E. Percival, Canterbury University College, Christchurch, New Zealand.

PARAPHOXUS Sars, new synonymy

Paraphoxus Sars, 1893: 148.
Pontharpinia Stebbing, 1897: 32.
Parharpinia Stebbing, 1899: 207.
Protophoxus K. H. Barnard, 1930: 335.
Trichophoxus K. H. Barnard, 1930: 336.
Metharpinia Schellenberg, 1931: 65.

Examination of specimens of *Paraphoxus oculatus* Sars from Norway, the type species of the genus, revealed a biarticulate first maxillary palp and not a uniarticulate condition as shown by Sars in 1893. Historically, the other genera in the above synonymy have been separated from *Paraphoxus* by the possession of a biarticulate palp; therefore, this distinction is no longer valid.

The genera *Parharpinia* and *Protophoxus* were already fused to *Pontharpinia* by Pirlot (1932). The genus *Trichophoxus* was based on the elongated fifth articles of the gnathopods, but the writer has found that this is not unusual in paraphoxids and of no generic value. *Metharpinia* was founded on species bearing narrowed rostrums (also characteristic of

Trichophoxus) but the writer has found species which intergrade between the broad and narrow rostral types. However, it is useful to separate the two groups as subgenera, using the names *Paraphoxus* s.s. (broad rostrums) and *Trichophoxus* (narrow rostrums).

SPECIFIC CRITERIA IN THE GENUS PARAPHOXUS

Much of the apparent confusion in phoxocephalid systematics stems from the superficial lack of specific criteria. It is often the case that two species may appear quite similar with respect to head, gnathopods, peraeopods, uropods, and third epimera, which are the characters most useful systematically in other amphipods. Additional specific differences have been sought and one of the most important of these is the condition of the epistome. The presence of an acutely produced epistome in one of a pair of otherwise similar species has been most useful in calling attention to their distinctness and to a need for statistical measurement of other minor differences. *Pontharpinia epistoma* Shoemaker, 1938, was the first phoxocephalid described with a produced epistome. In the materials at hand are nine other new species bearing produced epistomes of varying extent, several of which are otherwise scarcely distinguishable from relatives in which the epistome lacks an anterior process.

Unfortunately, many of the existing specific descriptions of paraphoxids are practically useless and all species should be re-examined according to the following list of criteria. Due to the fact that seemingly minute differences may have specific value, drawings are far more useful than words.

The criteria deemed important by the writer and for which figures should be drawn are:

1. Dorsal shape of head and rostrum.
2. Size of eyes in both sexes in relation to size of head.
3. Shape of epistome from lateral view.
4. Presence or absence of a distal spine or claw on palp article 4 of the maxilliped.
5. Shape and size of articles 5 and 6 in both pairs of gnathopods.

6. Stoutness of spination on article 5 of peraeopods 1 and 2.
7. Unusual features of the coxae.
8. Ornamentation and proportions of the articles of peraeopods 3, 4, and 5.
9. Configuration and armature of pleonal epimera 2 and 3.
10. Spination of uropods 1 and 2.
11. Proportions of uropod 3. The length of the inner ramus on the female is quite variable interspecifically, as is the length and shape of article 2 of the outer ramus.
12. Breadth, apical shape, and armature of telson.
13. Breadth and dorsal depression of body.

Paraphoxus milleri (Thorsteinson), new combination, new synonymy

Pontharpinia milleri Thorsteinson, 1941: 82.
Pontharpinia longirostris Gurjanova, 1938: 263 (=Homonym, not Schellenberg, 1931).
Pontharpinia robusta Gurjanova, 1938: 262 (=Homonym, not Holmes, 1908).

A study of the variability of this species in eastern Pacific waters indicates that the names above should be fused. Both of the earlier names of Gurjanova are junior homonyms so that the only available name is *P. milleri*.

Paraphoxus obtusidens (Alderman), new combination, new synonymy

Pontharpinia obtusidens Alderman, 1936: 54.
Pararpinia (sic) *pontarpioides* Gurjanova, 1953: 229.

The description and figures of the junior synonym represent one form of this variable northern Pacific species.

Paraphoxus sinuatus (K. H. Barnard), new combination, new synonymy

Parharpinia villosa, Schellenberg, 1931: 75 (not Haswell, 1879).
Parharpinia sinuata K. H. Barnard, 1932: 103–104, fig. 52.

The examination of the type of *P. villosa*, from Australia, by Dr. Keith Sheard and of Schellenberg's material, from South America, by the writer revealed several important differences in the South American species. The *Parharpinia villosa* of Schellenberg differs from the holotype by: (1) article 5 of gnathopod 1 shorter than 6, as opposed to longer than 6 in *P. villosa;* (2) article 6 of gnathopod 1 with parallel margins, as opposed to rounded in *P. villosa;* (3) article 4 of peraeopod 3 is only two thirds as wide as article 2 while it is fully as wide as article 2 in *P. villosa;* (4) article 2 of peraeopod 5 has the posterior edge with sparse and poorly setose serrations while in *P. villosa* it has numerous fine crenulations with long setae; (5) the peduncle of uropod 1 has numerous spines of strikingly different sizes on the inner and outer margins, as opposed to sparse similar spines on both margins in *P. villosa;* (6) the inner ramus of uropod 2 bears spines but lacks them in *P. villosa.*

Statistical analysis of large collections may show these differences to be of subspecific value only; in any case the South American specimens need nomenclatural segregation. This is provided by K. H. Barnard's name, *P. sinuata*, which by its description, figures, size, and geographic location is shown to be conspecific with Schellenberg's material.

Paraphoxus tattersalli, new species

Pontharpinia villosa, Tattersall, 1922: 4 (not Haswell, 1879*a*).

The clear figures published by Tattersall show striking divergence from the type of *P. villosa* which was examined by Dr. Sheard. Some of the many differences of *P. tattersalli* are: (1) gnathopods 1 and 2 differ in size greatly, while in *P. villosa* they are similar in size; (2) the short fifth articles of the gnathopods; (3) the very narrow plate of article 2 of peraeopod 5 compared with the very broad one in *P. villosa;* (4) article 4 of peraeopod 3 is half as wide as article 2, while in *P. villosa* it is fully as wide as article 2.

Paraphoxus stebbingi, new species

Pontharpinia pinguis, Stebbing, 1897: 33; Stebbing, 1906: 146 (in part); Stebbing, 1910: 635 (in part) (not Haswell, 1879*b*).

Stebbing's clear description and figures reveal several differences from the type of *P. pinguis* (Haswell), which was examined for the writer by Dr. Sheard. *Paraphoxus stebbingi* differs from *P. pinguis* by: (1) a minute cusp on the posteroventral corner of the third pleonal epimera, as opposed to a long, upturned cusp in *P. pinguis*, overlooked by Haswell in his description of the species; (2) the very elongated fifth articles of the gnathopods; (3) the narrow sixth articles of the gnathopods as opposed to the broad articles in Haswell's original drawing of *P. pinguis* (the sixth articles are missing on the type specimen of *P. pinguis*).

Heterophoxus oculatus (Holmes), new combination, new synonymy

Harpinia oculata Holmes, 1908: 521.
Harpinia affinis Holmes, 1908: 523.
Heterophoxus pennatus Shoemaker, 1925: 22.

The types of *H. oculata* and *H. affinis* in the U. S. National Museum were examined and found to be conspecific with *H. pennatus*. The name *oculatus* was chosen from Holmes' names on the bases of page priority, the better condition of the holotype, and the appropriateness of the name, referring to an animal with eyes.

Heterophoxus ophthalmicus (Schellenberg), new combination

Harpinia ophthalmica Schellenberg, 1925: 136.

Schellenberg's description is that of an heterophoxid, as shown by the presence of eyes, the ensiform process on the second antenna and the short fourth maxillipedal palp article bearing a long seta. However, on the basis of the description, the species cannot be differentiated from others in the genus *Heterophoxus*.

Proharpinia stephenseni (Schellenberg), new combination

Heterophoxus stephenseni Schellenberg, 1931: 73.

The type species of *Proharpinia* is *P. antipoda* Schellenberg, (1931: 80). Specimens of both *P. antipoda* and *H. stephenseni* were compared and found to be congeneric. The genus *Proharpinia* differs from the genus *Heterophoxus* only by: (1) the lack of an ensiform process on antenna 2; (2) the presence of a cusp on the lower anterior corner of the head. *Proharpinia stephenseni* may be separated from *P. antipoda* by: (1) the lack of teeth on article 2 of peraeopod 5; (2) a shorter tooth on the third pleonal epimera.

Proharpinia hurleyi, new species

Harpinia obtusifrons, Chilton, 1909: 619 (in part) (not Stebbing, 1888); Stephensen, 1927: 306 (not Stebbing, 1888).
Heterophoxus stephenseni, Hurley, 1954: 589 (not Schellenberg, 1931).

Some of Schellenberg's original material of *H. stephenseni* from South America (see previous species) and Hurley's specimens from New Zealand were compared and both were found to belong to the genus *Proharpinia*. However, the New Zealand specimens are a distinct species and differ from the *P. stephenseni* of South America by: (1) the presence of minute serrations on the posterior edge of peraeopod 5, article 2; (2) the longer tooth on the third pleonal epimera; (3) the stouter, longer spines on the telsonic apices; (4) the longer rostrum, smaller eyes of the female, and the smaller process on the lower anterior corner of the head; (5) the relatively longer sixth articles and more oblique palms of the gnathopods.

Chilton's specimens reported in 1909 (deposited at Canterbury University College) were examined and some were found to be *P. hurleyi* while the rest could not be identified. The reference of Stephensen (1927) was originally included as a part of the synonymy of *Heterophoxus stephenseni* by Schellenberg

(1931) but it is clear from Stephensen's figures that the material belongs with *P. hurleyi*.

A ZOOGEOGRAPHIC NEED FOR THE PROVISIONAL USE OF THE NAME HARPINIOPSIS

The type species, *Harpiniopsis similis,* of this monotypic North Atlantic genus, described by Stephensen (1925) was submerged in the genus *Harpinia* by Gurjanova (1951).

The genus *Harpiniopsis* differs from *Harpinia* Boeck mainly by the very elongated male second antennae, a criterion generally true of all phoxocephalids, except for the specialized Harpinias. Although the writer deplores the use of secondary sexual criteria on which to base genera, he favors the retention of the name *Harpiniopsis* to designate a special group of harpiniids which may have important zoogeographic meaning.

The presence of only one species of *Harpiniopsis* in the rather well-explored northeastern Atlantic, compared with at least five undescribed species discovered by the writer in the eastern Pacific Ocean, is one example of the sparse representation of certain phoxocephalid genera in European Atlantic faunas. Another example of this is the presence of only one species of *Paraphoxus* in the northeastern Atlantic compared with several dozen species in the Pacific Ocean. On the other hand, the specialized genus *Harpinia*, which may have a *Harpiniopsis*-like ancestor, has many species in the European Atlantic but none in the tropical and temperate Pacific.

These facts lead to the suggestion that the Pacific Ocean, which is abundantly supplied with basic types of phoxocephalids such as *Paraphoxus* and *Harpiniopsis*, was the evolutionary center for the group. The only species of *Paraphoxus* in the northeastern Atlantic is also present in the northern Pacific, suggesting that it was the only one which successfully migrated to or survived in that part of the Atlantic. Only one species of *Harpiniopsis* survived in the north Atlantic, while its more specialized relative, *Harpinia*, probably

evolved in and dominated the northeastern Atlantic phoxocephalid fauna. In light of the cold water habitats of the species of the genera in question, the migration pathway for these events undoubtedly occurred north of the American or Asian continents.

In the western Atlantic Ocean, along the warmer eastern shores of the Americas, is a *Paraphoxus* fauna closely allied and in some cases identical specifically with that in the tropical and semitropical eastern Pacific Ocean. It is of considerable interest that none of these paraphoxids has appeared in the warmer eastern Atlantic, suggesting difficulty or slowness of migration, or the inability to compete in the harpiniid-dominated eastern Atlantic.

Although these facts are meager they nevertheless point to a pressure of migration from the generalized and mixed phoxocephalid faunas of the northeastern Pacific Ocean to the more specialized, sparser, and geographically isolated faunas of the Atlantic Ocean.

It is advisable to retain the name *Harpiniopsis* for a group of species which are closely related to a theoretical precursor of the genus *Harpinia* and which, through distributional studies, may shed further light on the relationships of Pacific and Atlantic faunas.

KEY TO THE EXISTING GENERA OF PHOXOCEPHALIDAE[3]

1. Peraeopod 3, article 2 more than twice as wide as article 3.....................2
1. Peraeopod 3, article 2 about as wide as article 3...........................6
2. Maxilla 1, palp biarticulate...........3
2. Maxilla 1, palp uniarticulate..........4
3. Antenna 2, flagellum multiarticulate, gnathopods 1, 2 similar in size. **Paraphoxus**
3. Antenna 2, flagellum biarticulate, gnathopod 1 much larger than 2... **Joubinella**

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[3] The genus *Phoxocephalopsis* Schellenberg, 1931, was placed in the family Haustoriidae by K. H. Barnard, 1932, although it is intermediate between that family and the Phoxocephalidae.

4. Mandible, molar bearing ridges and cusps ....**Phoxocephalus**
4. Mandible, molar smooth or with a few spines.........................5
5. Eyes present, maxillipedal palp article 3 unproduced..............**Metaphoxus**
5. Eyes absent, maxillipedal palp article 3 produced conically.......**Leptophoxus**
6. Eyes absent.......................7
6. Eyes present.......................9
7. Head with dorsal crest, uropod 2 with apical ramal spines......**Pseudharpinia**
7. Head lacks dorsal crest, uropod 2 lacks apical ramal spines.................8
8. Antenna 2 in male very short.......... ....**Harpinia**
8. Antenna 2 in male as long as body..... ....**Harpiniopsis**
9. Antenna 2 with basal ensiform process.. ....**Heterophoxus**
9. Antenna 2 lacks basal ensiform process.. ....**Proharpinia**

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Studies on Luminescence in Marine Snails

Y. Haneda[1]

AMONG THE GASTROPODA Opisthobranchiata certain genera of the Polyceridae, Tethyidae, and Phillirhoidae are luminous. Among the Gastropoda Pulmonata two luminous species are known: *Latia neritoides*, fresh water limpets, first discovered in New Zealand by Suter (1890), and *Dyakia striata*, land snails, found by myself in Singapore in 1946.

Luminous species of Gastropoda Prosobranchiata are very rare, however, according to E. N. Harvey in his book *Bioluminescence* (1952). Turner in 1948 informed him by letter that *Tonna galea* Linné, a marine snail, is luminescent. When this snail moves through water with its foot well extended, it emits a greenish-white light. A species of doubtful luminescence is also found among the heteropods (Pterotracheata) according to Keferstein in Bronn's *Tierreich* (1862–1866).

We have found two species of luminous marine snails on Borawazawa Beach, at Suyeyoshi Village, which is located on Hachijo Island, 157 miles south of Tokyo. This discovery was made during ebb tide on April 23, 1953. While I was strolling on the beach with an acquaintance, Mr. H. Okuyama, teacher of Suyeyoshi Primary School, he chanced to raise a stone, and we were both astonished to find under it some small marine snails which were emitting light as they rolled in the water. Excitedly we collected many specimens, examining them closely to find out if

these marine snails were really luminous, or whether their luminescence was due only to their having eaten some luminous matter or to infection with luminous bacteria.

As a result of subsequent experiments, I decided that these snails were true luminous animals, possessing luminous organs on their mantles (Haneda, 1955).

During a trip to the Luminescence Conference at Pacific Grove, California, for the meeting of March 29–April 1, 1954, I had the opportunity to continue my studies of these interesting animals. I collected another species of luminous snails on Waikiki beach, Oahu, and one other species on Onekahakaha beach, Hawaii, and on the beach at Key West, Florida (see Haneda, 1955).

ACKNOWLEDGMENTS

[1] Yokosuka City Museum, Yokosuka, Japan. Manuscript received November 16, 1956.

to Mr. Y. Shinoda and Mrs. S. Nunes, for their assistance in collecting materials during my stay in Hawaii; to Mr. H. B. Summers, for having assisted me in the preparation of the manuscript; and to Mr. H. Okuyama of Naka-nogoh Primary School of Hachijo Island who assisted in collecting materials, and whose keen observations made this discovery of luminescence in *Planaxis* possible.

I would also like to express my warmest appreciation to the Committee of the Luminescence Conference, for inviting me to participate in the meetings of March 29–April 1, 1954 at Pacific Grove, California, which gave me the opportunity to collect many American specimens.

MATERIALS

The luminous marine snails which I have collected all belong to the genus *Planaxis* of the Planaxidae and are comparatively small. The various species of this genus in which I have observed luminescence are shown in Table 1.

All of these animals are capable of living in aquaria for a long time, usually up to two to three months, and in some cases as long as one year. I collected many specimens in April at Hachijo Island and brought them to

FIG. 1. *Planaxis virgatus.*

FIG. 2. *P. labiosus.*

my laboratory in a small bottle. These animals lived in a small dish until the end of August of the same year, during which period the water was changed several times. I twice air mailed several living specimens of *Planaxis virgatus* in a small bottle of sea water to Dr. E. N. Harvey of Princeton University. The first time all the specimens were dead when Dr. Harvey received them. But the second time the specimens arrived alive.

I brought some specimens of the Hawaiian species in a small bottle of sea water to the Conference on Luminescence and demonstrated their luminosity to Dr. Harvey and other members present. Afterward I took those specimens on my journey in the United States and brought them back to my laboratory about two months later. The snails lived in a small aquarium until March 21, 1955, and some of them hatched larvae, but luminosity in these larvae was not observed.

OBSERVATION OF LUMINOUS PHENOMENA

Under natural conditions, the light of these animals cannot be seen well; they will emit light only under strong stimulation. If many specimens are placed in a bottle and are well shaken in the dark, some of them become luminous and twinkling. The light usually continues one or two minutes after stimulation, then gradually disappears. But if the body of the snails is irritated, the light re-
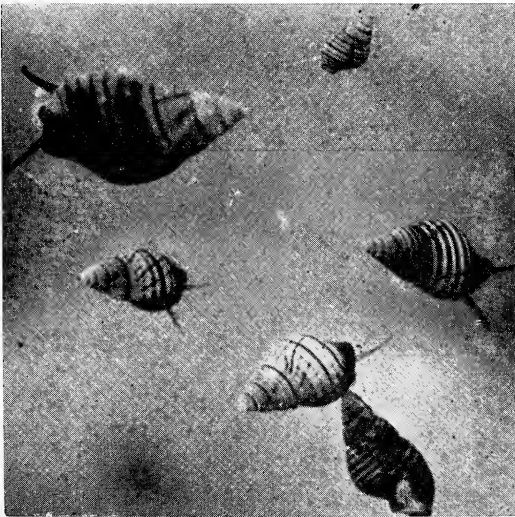
SPECIES	PLACE	DATE	SIZE OF SHELL		REMARKS
			Height, mm.	Diameter, mm.	
Planaxis virgatus Smith...	Borawazawa Beach, Hachijo I., Japan	April, 1953	8.0	4.0	Luminous
	Habu, Ohshima I., Japan	Oct. 1953			
P. periscelida Dall.......	Heta, Izu Peninsula, Japan	May, 1953	3.5	2.0	Luminous
P. longispira Smith......	Dogashima, Izu Peninsula Japan	Aug., 1953	6.0	2.8	Luminous
P. lineatus da Costa......	Waikiki Beach, Honolulu, Hawaii	March, 1954	10.0	5.2	Luminous
P. labiosus A. Adams....	Onekahakaha Beach, Hilo, Hawaii	March, 1954	10.0	5.0	Luminous
P. labiosus A. Adams....	Key West, Florida	April, 1954			
P. sulcatus Born.........	Shirahama, Wakayama Pref., Japan	April, 1955	15.0	10.0	Non-luminous

appears once again. After crushing the shell and removing the body of the snail, a low power magnification will show that the luminous part of its body is situated on the mantle in a limited area (Fig. 3). When the body is put into fresh water, the light on the mantle continues as a more prolonged glow. However, after 10 or 15 minutes in fresh water, the animal becomes weak and its light cannot be seen even after strong stimulation. If the body is placed on photographic film for a few minutes in the dark, an image of the light appears.

Observed under the microscope in the dark, the luminous area of the snail takes on the appearance of a night sky. Minute luminous points glimmer and twinkle like so many stars. The luminescence of this animal is intracellular; no luminous slime goes into the surrounding sea water. Among the six species of Planaxidae, which were examined, the following five have the same type of luminous organ: *Planaxis virgatus, P. longispira, P. periscelida, P. lineatus,* and *P. labiosus. P. sulcatus,* however, has no luminous organ at all.

EFFECTS OF TEMPERATURE

No effects are noticable to the naked eye in the intensity of luminescence in marine snails under thermostimulation. Through the use of the highly sensitive 1921 photomultiplier, followed by two stages of amplification feeding into a Brown recorder, however, the light intensity changes resulting from changes in temperature are readily discernible. I had the opportunity to make use of such equipment through the kind offices of Dr. Bernard L. Strehler of the Department of Radiobiology at the University of Chicago when I visited that institution in April, 1954. Our tests were extremely interesting. Contained in a small glass tube of sea water at a temperature of 15° C., the snails were placed near the photomultiplier and the temperature of the tube was raised and lowered in two successive cycles and the light intensity recorded.

From an initial centigrade reading of 15° C. the snails' temperature was raised to 45° C. and lowered to −10° C. in a period of less than 10 minutes. From this point the temperature was again raised gradually to 60° C. and lowered to 15° C. During the first cycle the maximum of relative light intensity was at 45° C. As the temperature decreased so did the intensity, until at −10° C. it could not be detected.

During the second cycle, however, the in-

tensity became progressively weaker after 30° C., despite an increase of temperature to 60° C. At this point the intensity had dropped to zero, and during the following decrease in temperature, it showed no discernible recovery. As far as could be determined, the snails had died at approximately 60° C.

STRUCTURE OF THE LUMINOUS ORGAN IN *Planaxis labiosus*

The luminous organ, situated on the dorsal part of the mantle in the limited area shown in Figure 3, is a translucent pale blue color when fresh. The external visible area of this luminous organ consists of many folds of luminous tissues which run parallel with each other. If the body is taken out of the shell and put into an aluminum morine solution (diluted 500,000 times) for a few minutes and then washed carefully in fresh water, it is possible, by observation with Yasaki's fluorescent microscope (1952), to see the beautiful

FIG. 4. Effect of temperature on *Planaxis labiosus* luminescence. (Numbers on the vertical axis are counts of the recorder of the photomultiplier.)

blue-green fluorescent light which these luminous tissues emit. The structure of all five luminous species of *Planaxis* is practically the same: the luminous cells are restricted to this area of the mantle.

HISTOLOGY

Since the luminescence of this snail is localized in a limited area on the mantle and the animal is small in size, the whole body was preserved in a fixative of sea water prepared with formalin and Bouin's solution. The material was cut in 10 μ sections both longitudinally and transversely. The stains used were haematoxylineosin and aluminum morine. The appearance of the longitudinal section of the mantle is much like that of a comb. On the inside of the mantle, where the luminous area is situated, there appeared many pleats arranged in parallel, but it was impossible to determine whether or not these pleats contain luminous cells. However in the luminous area of the mantle, under the thin epithelium, there appeared many cellular masses, which very probably contain the photogenic tissues of this body. Each of these masses consists of small, closely packed cells.

FIG. 3. Dorsal view of the body of *Planaxis labiosus*, removed from the shell. *l*, Luminous area of mantle; *m*, mantle; *col*, collar; *p*, propodium; *t*, tentacles.
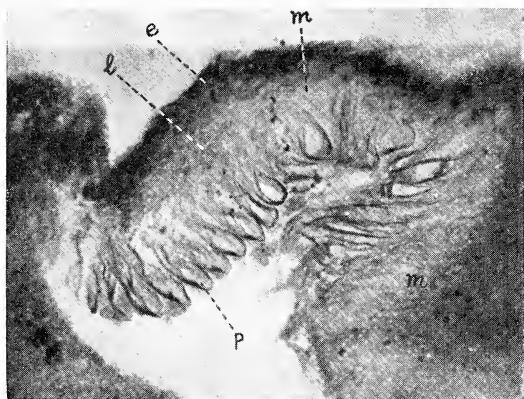
FIG. 5. Longitudinal section of the mantle containing luminous tissue of *Planaxis labiosus*. *l*, Luminous tissue; *m*, mantle; *p*, pleats; *e*, epithelium.

The character of these cells indicates that the luminescence must be intracellular.

BIOCHEMISTRY

Further experiments to relate luminescence to biochemistry were carried out as follows. A number of the snails were removed from their shells and thoroughly dried. They were then ground in a mortar and moistened with water, but luminescence did not appear. A negative luciferin-luciferase reaction was obtained by mixing hot water and cold water extracts of the crushed bodies. If the cold water extract of crushed luminous snails is allowed to stand until the luminescence of the extract disappears, it will not recover its luminescence even when ATP (Adenosinetriphosphate) is added.

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Contributions to the Knowledge of the Alpheid Shrimp
of the Pacific Ocean
Part III. On a Small Collection from Onotoa, Gilbert Islands[1]

ALBERT H. BANNER[2]

THIS PAPER reports on a small collection of snapping shrimp made at Onotoa in the southern Gilbert Islands during the summer of 1951 by the members of the Coral Atoll Research team during the investigation of the total ecology of the atoll under the sponsorship of the Pacific Science Board with funds from the Office of Naval Research (Contract NR 160–165). Members of the team working on the ecology of marine animals were Dr. Preston E. Cloud, Jr. of the U. S. Geological Service, Dr. Donald W. Strasburg, Dr. John E. Randall, and myself. The latter three at the time were with the University of Hawaii.

The study of these shrimp was initiated under a grant administered by the U. S. National Museum and the Pacific Science Board under a contract between the Office of Naval Research, Biology Branch, and the National Academy of Sciences (NR 160–175); some help in the final phases of the study was gained through a grant from the National Science Foundation (NSF-G-1754). I also wish to acknowledge the aid that was given me in the field by Drs. Cloud, Strasburg, and Randall.

In order to save space and time in this paper, as in the second study, instead of giving complete synonymy and bibliographic references for each species, reference will be made to the earlier papers of the series whenever a species has been listed before.

Type specimens of the new species described in this paper will be deposited in the institution from which they were borrowed; those types in my personal collection will be deposited either in the U. S. National Museum or the Bernice P. Bishop Museum.

ONOTOA ATOLL

Onotoa is a small, relatively dry atoll in the southern portion of the Gilbert Islands. This portion is known also as the Kingsmill Islands. It lies at 1°47′ S., 175°29′ E. (north anchorage) and is slightly less than 12 miles long and 5 miles broad, while the land area, reaching along the eastern side of the lagoon, is only slightly more than half a mile wide at the broadest spot (Fig. 1). The windward or eastern side of the atoll has a broad reef flat varying from less than 1,000 to more than 2,000 feet in width; the outer edge of this flat is marked by a shallow trough, then a higher coralline ridge which breaks up into a series of well-developed surge channels; beyond the end of the surge channels is a narrow sloping shelf from 10 to 40 feet deep which drops off abruptly into deep oceanic water. The lagoon is shallow with the deepest measured point about 50 feet, while most of the lagoon area is less than 12 feet deep; large areas near the islands were exposed by low tides. The western edge of the lagoon was marked by an interrupted series of coral reefs growing to near the surface with shallow passes between them. The western edge of the atoll drops off into deep water almost as abruptly as does the eastern except off the northern anchorage to the west of the chief village. (Dr. Cloud has an extensive report on the physical and biological condition of the atoll in his 1952 report.)

COLLECTIONS AND HABITATS

Unfortunately the collections from Onotoa are not very extensive. An infected leg prevented me from collecting for about half of the 10 weeks we spent on the island, and in the short time remaining I had to devote full time to making the ecological survey, collecting snapping shrimps only as they appeared in the transects. Most of this small collection was lost in transit from Onotoa via Kwajelein to Hawaii and, eventually, only a small proportion of the shrimp collected at Onotoa arrived in Honolulu. Most of the specimens available for study were those collected by Dr. Cloud incidental to his studies on marine geology. However, small as the collection is, it is important for there have been no previous records from the Gilbert Islands.

On the windward reef a transect 20 feet wide was taken normal to the beach line and reaching to the coralline ridge, 750 feet to seaward. Because of the great diversity of habitats and the limitations of time no extensive transects were taken on the lagoon side, but the different shallow water habitats were sampled individually (see Banner and Randall, 1952).

The ecological notes on the stations from which shrimp were examined (it should be noted that alpheids were collected at almost all stations) are as follows:

A-1. Starting with division between beach rock and higher sand beach, at about 2.4-foot tide zone, reaching seaward 50 feet; substrate of consolidated reef limestone; many tide pools, the largest up to 20 feet long, 5 feet wide, and 6 inches deep; both exposed areas and bottoms of tide pools with scattered loose rocks up to a foot square and 6 inches thick.

A-2. 50–100 feet from beach line, about 2.2-foot tide zone; similar in nature to A-1, but with fewer and smaller tide pools.

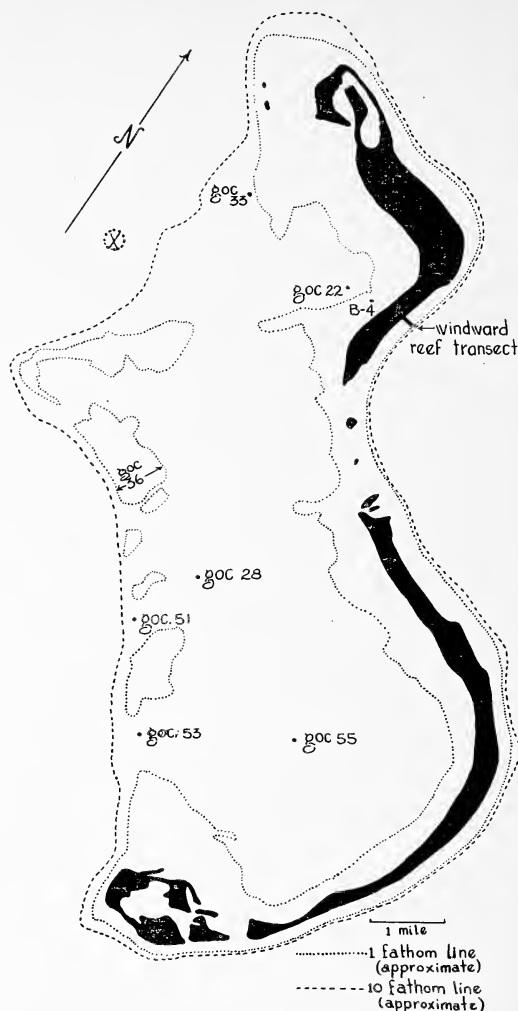A-3. 100–150 feet from beach line, about 2.0-foot tide zone; substrate similar to A-1, A-2.

FIG. 1. Onotoa, Gilbert Islands, showing localities of collections. Place indicated by X is approximately 1°47′ S., 175°29′ E.

A-6. 250–300 feet from beach line, about 1.4-foot tide zone; about 30 per cent of area covered by very shallow tide pools. Substrate changing to a coralline algal sheet overgrowing dead coral heads *in situ* with numerous small holes passing through sheet into cavities remaining between the coral heads.

A-7. 300–350 feet from beach line, about 1.2-foot tide zone; about 80 per cent of the area covered by 1-inch-deep tide pools that only drain on extreme low waters; substrate as in A-6, but carpeted by thick tufts of green

algae in which many animals live; some loose rocks, several feet across, under which most of the snapping shrimp were collected.

A-10–12. 450–600 feet from beach line, 0.8–0.4-foot tide zone; about 70 per cent covered with shallow tide pools; substrate, algal covering, rocks similar to A-7; collecting of shrimp done at random in area wherever larger rocks occurred.

B-4. On sandy lagoon beach, about 0.0–2.0-foot tide level, 400 to 1,000 feet from high tide line; snapping shrimp collected from heads of dead coral protruding above the sand beach.

The following stations were those made by Dr. Cloud in which alpheids were collected:

GOC-22. Station nearly in line with B-4 above, 1,200 feet from shore, about 4–6 feet deep at low tide; substrate similar to B-4, but with more living and dead coral.

GOC-28. Middle lagoon region, from reef patches from 6 to 14 feet deep.

GOC-33. On outer edge of outer or western reef growth; depth from surface (low tide) to about 24 feet; flourishing coral growth.

GOC-36. Across surface of outer or western reefs; depth less than 6 feet; extensive coral growth separated by sandy areas.

GOC-51. In pass through western reef front; collections from coral patches, mostly of living coral, rising from sandy bottom at 15 feet to within 8–10 feet of surface.

GOC-53. A pass similar to GOC-51, bottom at 18 feet, coral patches rising to within 4 feet of surface.

GOC-55. From deepest spot on lagoon, sounded at 50 feet; bottom sandy to muddy, with scattered low clumps of living and dead coral.

SYNALPHEUS Bate

Synalpheus carinatus (de Man), 1888

For synonymy see Banner, 1957.

LOCALITY: 5 specimens from GOC-53.

DISCUSSION: These specimens, from the same collection that yielded the obviously closely related *S. consobrinus* de Man, have not been assigned to any of de Man's three subspecies. The subspecies were erected primarily upon the size of the ova, which were reported by de Man to be 0.4–0.5 mm. long in one subspecies, 0.9–1.0 mm. in the second, and 1.2 mm. long in the third. Of these specimens, three were ovigerous with the egg diameters 0.6 by 1.0 mm., 0.65 by 1.1 mm., and 0.65 by 1.5 mm. It was also noted that the smallest eggs had the youngest embryos, while the largest had embryos near hatching. The other characteristics used by de Man in the separation of the subspecies are based on slight differences of variable characteristics, like the notch in the rostral carina, which in even these few specimens varied from well developed to almost nonexistent. Without other less variable characteristics to base the differentiation upon, with this group of specimens showing marked variation in the size of the ova, and with poecilogony well known among the synalpheids (see Coutière, 1899:444 *et seq.*) it appears that the division of the species into subspecies on these criteria is unrealistic.

Synalpheus amboinae (Zehntner)
Fig. 2

Alpheus amboinae Zehntner, Rev. Suisse de Zool. 2: 202, pl. 8, fig. 23 a, b, 1894.
Synalpheus amboinae de Man, Siboga Exped. 39a[1](2): 203, pl. 6, fig. 20, 1911.

LOCALITY: 3 specimens at GOC-53.

DISCUSSION: While these specimens are within the range of variation given by de Man (1911) and agree well with the descriptions of the species, they have been referred to this species with considerable doubts. They were collected at the same locality and at the same time as *S. consobrinus* de Man. These two nominal species differ in the presence of a tooth above the articulation of the large chela, and in slightly different proportions and armature of the telson. With the difference in the size of the specimens reported by de Man, one would suspect that
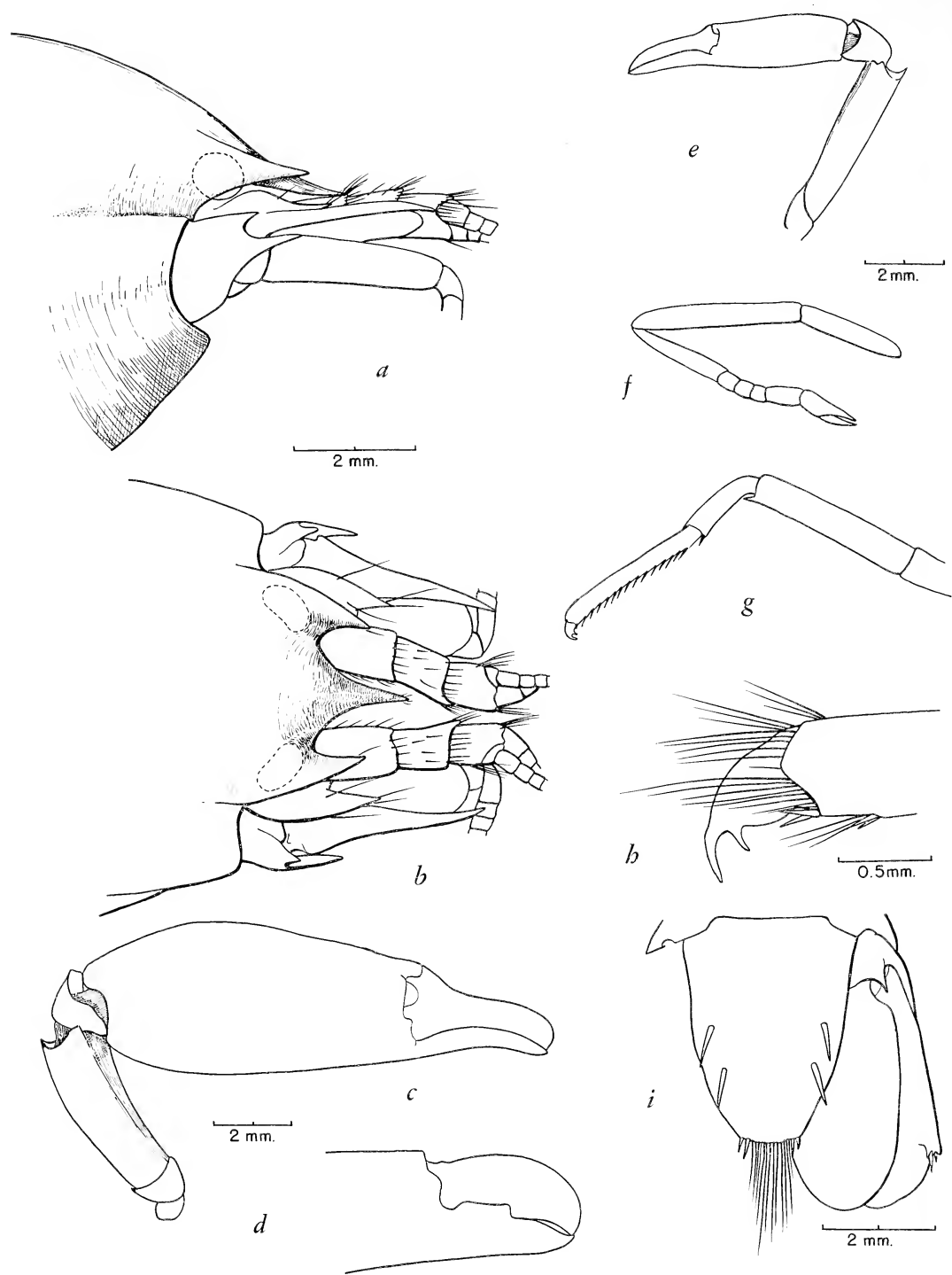
FIG. 2. *Synalpheus amboinae* (Zehntner). *a, b,* Anterior region; *c,* large cheliped; *d,* large chela, ventral view; *e,* small cheliped; *f,* second leg; *g,* third leg; *h,* third leg, dactylus; *i,* telson and uropods.

possibly the distinguishing characteristics may be the result of growth and therefore not of specific worth. However, in the absence of an intergrading series of specimens, the species has been permitted to stand.

Synalpheus consobrinus de Man, 1909

For synonymy see Banner, 1957.

LOCALITY: 8 specimens from GOC-53.

DISCUSSION: This group of specimens agreed well with the description and variations of de Man. In general they ran smaller than de Man's type, mostly 15 mm. long or less, yet the females were ovigerous. It is likely that these, together with the closely related *S. carinatus* (de Man) and *S. amboinae* (Zehntner), were collected from crinoids on the coral reef, but the exact data on their capture is lacking. In any case, it seems strange that three different but most closely related species would be living so close to each other in the same basic habitat, and for that reason alone the species should be suspect.

Synalpheus charon (Heller), 1861

Synalpheus charon obscurus Banner, 1956

For synonymy see Banner, 1956.

LOCALITY: 3 specimens at GOC-51, two of *S. charon charon*, one of *S. charon obscurus*.

DISCUSSION: The fact that in this locality two specimens of *S. charon charon*, an ovigerous female and a male, and one ovigerous female of *S. charon obscurus* were found casts some doubts as to the validity of the subspecies. It may indicate that the two forms are mere variations that breed together; it certainly indicates that the subspecies are not geographically distinct, as the other collections have indicated until now. However, as no intergrading specimens have been found and as the data of this collection do not indicate that the two subspecies might not maintain an ecological isolation, it has been decided to leave the subspecies standing.

Synalpheus paraneomeris Coutière, 1905

For synonymy see Banner, 1956.

LOCALITIES: 3 specimens at A-7; 5 specimens at GOC-51.

Synalpheus coutièrei Banner, 1953

For synonymy see Banner, 1957.

LOCALITY: 1 specimen at GOC-55.

Synalpheus pachymeris Coutière, 1905

Synalpheus biunguiculatus var. *pachymeris*, Coutière, Fauna and Geog. Maldive and Laccadive Archipelagoes 2(4): 873, pl. 71, fig. 9, 1905.

Synalpheus pachymeris de Man, Siboga Exped. 39a[1](2): 199, 1911.

LOCALITY: 1 ovigerous female from GOC-55.

DISCUSSION: This sole specimen agrees well with Coutière's description and figures except that the orbital teeth are more pointed, with their outer lateral margins concave, similar to that figured by de Man for *S. quadrispinosis* de Man (1911: pl. 12, fig. 57).

Synalpheus quadrispinosus de Man

Synalpheus quadrispinosus de Man, Nederland. Dierk. Ver., Tijdschr. II, 11(4): 298, 1910; also, Siboga Exped. 39a[1](2): 285, pl. 12, fig. 57, 1911.

Synalpheus quadridens de Man, Nederland. Dierk. Ver., Tijdschr. II, 11(4): 299, 1910; also, Siboga Exped. 39a[1](2): 284, pl. 12, fig. 56, 1911.

LOCALITY: A male and an ovigerous female from GOC-55.

DISCUSSION: de Man described as separate species two closely related forms, both characterized by four spines on the posterior margin of the sixth abdominal segment. They were separated by a series of characteristics, but principally by the form of the orbital teeth and the proportions of the small chela.

The first species, *S. quadrispinosus*, was represented in the Siboga collections by three mature and two immature specimens; the second, *S. quadridens*, by a sole ovigerous specimen lacking the large chela.

In this collection there is a single pair of specimens in good shape (although the male is lacking the small chela) which exhibits a perplexing confusion of the supposedly distinguishing characteristics of the two species as separated by de Man.

Rostrum and orbital hoods: Both specimens are very similar to *S. quadridens*, with the orbital teeth heavy and inflated.

Antennular peduncles: In both specimens the antennular peduncle is assymetrically developed, with the total lengths of the peduncles approximately the same, but with the basal article of one about 1.3 times the length of the other; however, in general appearance the articles are slender as reported for *S. quadrispinosus*. The stylocerite, to the contrary, is shorter and heavier like that of *S. quadridens*.

Antennae: In the male the scaphocerite is shorter than that of *S. quadrispinosus* (which had the shorter scaphocerite of the two species), while in the female it is longer than *S. quadridens*. The carpocerite is shorter in the male than *S. quadridens* (which had the shorter carpocerite), while in the female the article is long as in *S. quadrispinosus*.

Large chela: In *S. quadrispinosus*, the only species with the large chela described, the chela had a breadth of 0.34 its length, the fingers occupied the distal 0.27 of the length (recalculated from de Man), and there was a rounded-to-acute tooth above the dactylar articulation. In both of these specimens the proportions are exactly the same, with the breadth 0.25 the length, and with the fingers occupying the distal 0.26 the entire length of the chela. In the male the tooth above the dactylar articulation is heavy and very conspicuous; in the female it is less pronounced and more gradually rounded.

Small chela: This is present only in the fe-

male, where the carpus equals 0.33 the length of the chela; the chela is 3 times as long as broad, with the fingers occupying the distal 0.4. These proportions are close to those of *S. quadrispinosus*, but not exactly the same.

Third leg: In the merus, where the greatest differentiation occurs, the male is 3 times as long as broad, like *S. quadridens*, and the female is 3.8 times as long as broad, like *S. quadrispinosus*.

Sixth abdominal segment: In the male the lateral teeth are narrow and acute like *S. quadrispinosus*, while in the female they are broader and more rounded like *S. quadridens*.

Telson: The proportions are given in the table below:

	MALE	FEMALE	*S. quadri-spinosus*	*S. quadridens*
Length/breadth at base	1.3	1.3	1.5*	1.4*
Breadth at base / Breadth at tip	1.7	2.0	2.1–2.2	2.0
Length/breadth at tip	2.3	2.5	3.2–3.4	2.8

(*Ratios calculated from other ratios.)

From this it can be seen that the telson most closely approached that described for *S. quadridens*.

In summation, the specimens at hand are quite similar to *S. quadridens* in five characteristics, and to *S. quadrispinosus* in five other characteristics. Even if these were not a cohabiting pair—which they probably were, considering that they were collected together —their essential similarities would not permit them to be considered as other than a single species. Their similarities to both *S. quadrispinosus* and *S. quadridens* should establish their close relationship to both of de Man's species and their variable and inconsistent differences with both of de Man's nominal species destroys the validity of de Man's criteria for separation of the two forms. The only conclusion that may be drawn logically is that *S. quadridens* is a synonym (by page priority in the original description) for *S. quadrispinosus* and that *S. quadridens* is a variable species.

ALPHEUS Fabricius

Megacheles Group

Alpheus oahuensis Banner, 1953

Fig. 3

For synonymy see Banner, 1956.

LOCALITY: 1 specimen at GOC-51.

DISCUSSION: It is with considerable doubt that this specimen, a 11 mm. male, is assigned to this species. The rostral front, assymetrically developed in this specimen, is the same as that of *A. oahuensis*, but the articles of the antennular peduncles are shorter and relatively broader. The merus of the large chela is also slightly heavier, and the tooth on the distal inferior margin is rounded and without an acute tooth. The chela itself is of the same basic form, but more slender in this specimen, and the teeth flanking the articulation of the dactylus are not as well developed. In the small chela the greatest differences occur, for there the fingers are equal in length to the palm, instead of being 1.4 times as long, and are not thin and markedly curved, and do not bear the rounded ridge like those of *A. oahuensis*. The second legs are lacking. In the third legs the armature is similar but the legs are

thinner, with merus 6 times as long as broad instead of 3.4 times; the inferior unguis of the dactylus is smaller.

But in spite of these differences in proportion, the general appearance of the two forms is quite similar, and these differences may be due to growth differences, for the type is 27 mm. long. Moreover, some variation along these lines was found in the paratypic series from Hawaii. However, with only one specimen from Onotoa, it is impossible to decide whether these differences are from individual variation, or from growth, or are constant differences that would be worth subspecific or specific rank.

Alpheus collumianus medius Banner, 1956

For synonymy see Banner, 1956.

LOCALITY: 2 specimens at GOC-51.

Machrochirus Group

Alpheus gracilis var. **simplex** (Banner), 1953

For synonymy see Banner, 1956.

LOCALITY: 1 specimen from GOC-51.

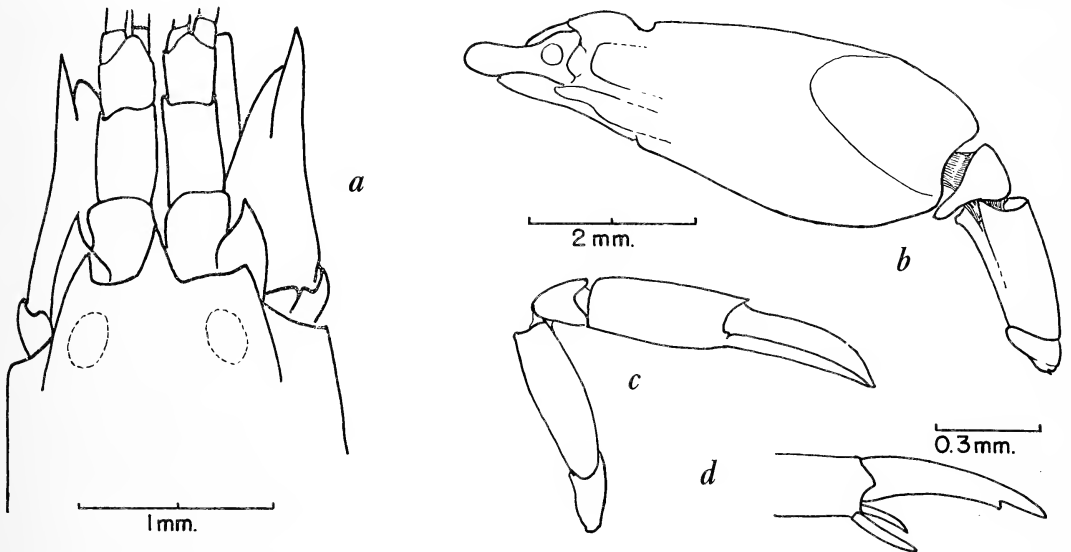DISCUSSION: This single specimen agrees

FIG. 3. *Alpheus oahuensis* (Banner). *a*, Anterior region; *b*, large cheliped; *c*, small cheliped; *d*, dactylus, third legs.

well with the specimens from Hawaii except that the dactylus of the third leg, instead of bearing a smooth convexity, carries an exceedingly small secondary unguis similar to but smaller than that found in *C. brachymerus* Banner (1953: fig. 17j). The external spine of the uropod is colorless.

In considering the specimens from Saipan, Arno, and Onotoa, the question arises as to the taxonomic level of this form. Obviously it is closely related to the *A. gracilis* of Heller, but whether it should be considered as a separate species, as a geographical subspecies, or as a variant—as it is now described—of the basic species, cannot easily be determined. On the basis of the Hawaiian specimens alone it would appear to be a separate species, or at least a subspecies; however, the specimens are from wide-spread localities. Yet none of these extra-Hawaiian forms are exactly like the specimens from Hawaii. It is possible that each of the studied archipelagoes have populations that could be interpreted as separate subspecies; certainly these variations appear to validate the consideration of these or the Hawaiian form as separate species. Yet the samples from the other archipelagoes have not been extensive enough to draw any conclusions about the populations, and many areas of the Pacific have not been sampled at all. Therefore the form is left as it was described originally with a tentative infrasubspecific designation.

Alpheus ventrosus Milne Edw., 1837
Fig. 4

For synonymy see Banner, 1956.

LOCALITIES: 2 specimens at GOC-22, 1 at GOC-33, 2 at GOC-36, 7 at GOC-51.

DISCUSSION: This group of four specimens from GOC-51, together with specimens from Saipan and Arno, present an almost complete intergradation between the small (8.5 mm.) form described as *A. latipes* and *A. ventrosus* which reaches a length of more than 40 mm.

While *A. latipes* as described was similar in general configuration to *A. ventrosus*, the two were distinctly separated by a number of characteristics. In the front of the carapace in *A. latipes*, the rostral carina was narrow and sharp and the orbital teeth were confluent with the front of the carapace, instead of having a flattened rostral carina and having the orbital teeth demarked medially from the margin of the carapace as is a characteristic for *A. ventrosus*. The antennular peduncles and the second and third legs were relatively broader in *A. latipes*. The fingers of the large chela were relatively shorter and the merus of the large and small chela were feebly armed or completely unarmed in *A. latipes*, instead of bearing up to four or five strong spines as in *A. ventrosus*. The dactylus of the third leg was abruptly curved and strongly acute in *A. latipes*, while in *A. ventrosus* the dactylus was of a peculiar blunt form, with a growth on the tip that was reminiscent of a horse's hoof. (Compare figs. 27, 28, Banner, 1953.)

Yet this group of specimens, ranging in size from 8.2 mm. to the adult size, shows an almost perfect intergradation in all of these characteristics. Two of the most marked and most easily observed characteristics, the form of the rostral carina and the form of the dactylus of the third legs, were chosen for detailed study and illustration. The four smaller specimens came from the station mentioned above; the last specimen came from the author's collection from Saipan.

In the 8.2 mm. specimen, the parts are almost identical to those described for *A. latipes;* if anything the dactylus of the third leg is slightly thinner. In the 9.7 mm. specimen the rostral carina does not change, but the dactylus is developing some extra superior and inferior thickenings. In the 10.8 mm. specimen the rostral carina still remains constant, but the dactylus is definitely growing thicker, the hook smaller, and a superior and inferior ridge is becoming more marked. In the 15.4 mm. specimen the interorbital portion of the rostral carina is broader and flatter,

but it still remains a sharp ridge on the anterior portion of the rostrum; the dactylus retains only a trace of the hook, the superior ridge is well developed, and the "hoof" is developing; the last spines of the propodus are thickening, but remain acute. Finally, in the 16.2 mm. specimen, the rostral carina is flattened to the tip of the rostrum, but still not as broad as in the full-sized adults; the dactylus has the structure and proportions of the adult; the last spines of the propodus are broad, distally rounded, but are not yet excavate on the tips, as are found in the mature specimens.

This easily recognizable species, possibly one of the most distinctive species of the genus, appears to have had at least four names applied to it: *A. lottini* Guérin, 1826–1830 (by Stebbing and Barnard, see below); *A. ventrosus* H. Milne-Edwards, 1837; *A. laevis* Randall, 1839; and finally, as discussed above, *A. latipes* (Banner), 1953. Unfortunately the three early names were published with short and generalized descriptions; only the first description carried a figure, and this figure appears to have been inaccurate.

The type specimen of Randall for *A. laevis* probably is lost with the rest of the early types at the Philadelphia Academy of Science, but there is only one species from Hawaii, the type locality, that meets the qualifications of his description including that of size ("length about 1½ inches"). This species is the one now known as *A. ventrosus* (see Banner, 1953: 84, fig. 28).

The type of Milne-Edwards has never been formally redescribed, but its characteristics are known. In *Les Alpheidae* (1899) Coutière discusses and figures specimens that he identifies as *A. laevis* Randall (figs. 54, 201, 251, 263, 307, 324, 325), a form plainly identical with the species from the Hawaiian Islands that has been known as either *A. laevis* or *A.*

FIG. 4. *Alpheus ventrosus* Milne-Edwards, to show developmental stages in the form of the rostrum and dactylus of third legs. *a*, An 8 mm. specimen; *b*, a 9.7 mm. specimen; *c*, a 10.8 mm. specimen; *d*, a 15.4 mm. specimen; *e*, a 16.2 mm. specimen; *a–d*, from Onotoa, *e*, from Saipan; carapaces and dactyli with separate scales. (Note: Dactyli are in differing rotation.)
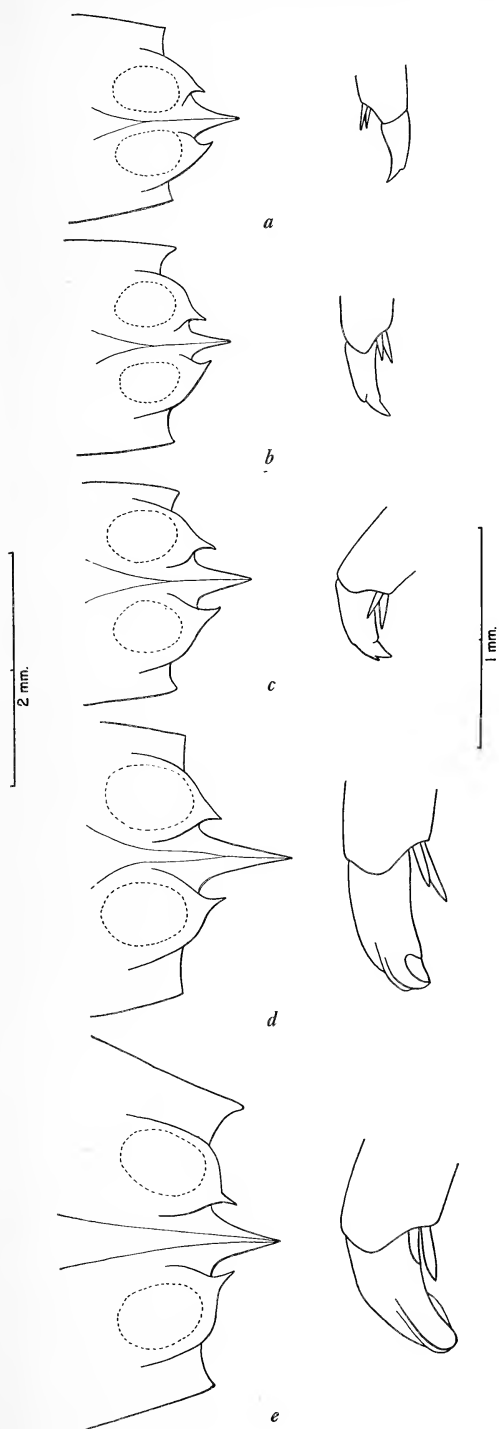
ventrosus. Especially noteworthy are the figures of the dactyli of the third to fifth legs (fig. 324, 325), a characteristic unique within the genus. Then Coutière (1905: 882) reported, "L'examen des types de H. M. -Edwards ne permet aucun doute sur l'identite de l'*A. ventrosus* et de l'espece . . . *A. laevis* . . . Randall." There appears, therefore, no question but that the two names refer to the same species.

However, there is considerable question whether the form described as *A. lottini* by Guérin is this species. Milne-Edwards in his original description of *A. ventrosus* (1837: 353) concludes by saying, "L'Alphée de Lottin dont il a été publié une bonne figure, mais dont la description n'a pas encore paru [the named figure was published about 10 years before the printed description, and in the meantime Milne-Edwards published his work] paraît être très-voisine de l'espèce précédete." Stebbing (1915: 82) states, "But the description of *A. ventrosus* does not seem to justify any claim for the priority of that name over Guérin's *A. lottini*." He therefore used the name *A. lottini*. Barnard, in his work on the South African decapods (1950: 748, fig. 141), follows the name used by Stebbing.

However, while Guérin's description and figures do not show any great differences from the generalized description of Milne-Edwards, they do show differences from the form now recognized as *A. ventrosus* and from the types as re-examined by Coutière. In Guérin's figure, the rostrum in *A. lottini* reaches almost to the middle of the second antennular article, instead of to the distal part of the first article; the lateral spine of the scaphocerite is too prominent; the second article of the carpus of the second leg is about 6 times as long as broad instead of 1.5 times; the dactyli of the third to fifth legs are shown as definitely acute. In the description, the wrist of the large chela is described as elongate and cylindrical, instead of short and cyathiform, and the articles of the posterior legs also as cylindrical instead of compressed.

A most important difference is in the color, for the orange-red color of the specimens of this species is one of the most constant colors found in the family, yet Guérin figured it as a delicate lettuce green and described it, "Sa couleur est d'un jaune verdâtre dans l'alkool." It should be noted, too, that the figure does not show any orbital spines, yet Guérin reports these in his description.

It is possible, of course, that these differences are the result of inaccurate description and the types are actually identical; however, there is no reason to presume so, and until the time that Guérin's types are found and redescribed, the name *A. ventrosus* should be accepted. If the types of Guérin should be found to be identical with the species of Milne-Edwards, I would recommend that the little-known and almost never used earlier name be suppressed by the International Commission on Zoological Nomencalture in favor of the long accepted name of this, one of the most common species of the genus.

One other problem raised by Stebbing (*loc. cit.*) was concerned with the identity of the form that Bate called *A. laevis* Randall. "Bate's figure of *A. laevis* in the 'Challenger' report [1888: 555, pl. 99, fig. 3] cannot easily be reconciled with the species here in question." It is true that Bate neither figured nor described the peculiar unguis of the third to fifth legs, and he depicted the legs, especially the second legs, as much too thin, but otherwise the specimen appears to agree with *A. ventrosus*. Moreover, Bate's specimen came from Hawaii, and, as with Randall's specimen, there are no other species in Hawaii that agree even moderately well with the description and figures. It should be noted, also, that Bate shows dark spots on the superior surface of the large and small chelae, a characteristic of the species (cf. Banner, 1953: fig. 28 c, d, e).

The last question that might arise is whether the species identified by Stebbing and Barnard from South Africa as *A. lottini* is the same as *A. ventrosus*. Stebbing's brief description leaves little room for doubt, and Barnard's

excellent figures make it certain that the South African form does not differ in any significant fashion from the Pacific form.

Alpheus machrochirus Richters, 1880

For synonymy see Banner, 1957.

LOCALITY: 1 specimen at GOC-36.

Obesomanus Group

Alpheus lutini Coutière, 1905

For synonymy see Banner, 1956.

LOCALITIES: 1 specimen each at B-4, GOC-28, GOC-53, GOC-55.

Alpheus species

LOCALITY: 2 specimens from GOC-51.

DISCUSSION: These two specimens, both females, appear to be in either the *Obesomanus* group or the *Crinitus* group, and may be related to the complex containing the species *A. obesomanus* Dana, *A. microstylus* (Bate), and *A. lutini* Coutière. These specimens appear to be of a separate species, possibly new, but preliminary work on the variation in this complex indicates that the specific characteristics need re-evaluation. Therefore it has been considered wiser to defer judgement on these specimens until a later paper when the related species are considered.

Crinitus Group

Alpheus brevipes Stimpson

Alpheus brevipes Stimpson, Acad. Nat. Sci. Phila., Proc. 12: 30, 1860.
Crangon brevipes Banner, Pacific Sci. 7(1): 103, figs. 35, 36, 37, 1953 [neotype described].

LOCALITY: 2 specimens at GOC-51.

Alpheus bucephalus Coutière

For synonymy see Banner, 1956.

LOCALITY: 3 specimens at A-7.

DISCUSSION: These specimens exhibited a variation similar to those forms reported upon from Saipan.

Alpheus clypeatus Coutière

Alpheus clypeatus Coutière, Fauna and Geog. Maldive and Laccadive Archipelagoes 2: 897–898, pls. 81, 82, figs. 36, 36g, 1905.
Crangon clypeata Banner, Pacific Sci. 7(1): 107, figs. 37, 38, 39, 1953.

LOCALITY: 1 specimen at GOC-51.

Alpheus pachychirus Stimpson, 1860

For synonymy see Banner, 1956.

LOCALITY: 1 specimen at GOC-51.

Diadema Group

Alpheus diadema Dana, 1852

For synonymy see Banner, 1956.

LOCALITY: 1 specimen at GOC-36.

Alpheus lanceloti Coutière

Alpheus lanceloti Coutière, Fauna and Geog. Maldive and Laccadive Archipelagoes 2: 900, pl. 83, fig. 39, 1905.

LOCALITY: 1 specimen only from A-3.

DISCUSSION: This specimen, fortunately intact, agrees almost perfectly with the original description by Coutière. The only exception may be in the merus of the large cheliped, which Coutière shows as bearing four immovable denticles proximal to the terminal denticle, and which bears four short but heavy movable spines in this specimen. It should also be noted that the merus of the third leg on one side is like that of the type bearing three movable spines, while on the other side there are four such spines.

Alpheus gracilipes Stimpson, 1860

For synonymy see Banner, 1956.

LOCALITY: 2 specimens from GOC-22.

Alpheus paracrinitus (Miers)
bengalensis Coutière, 1905

For synonymy see Banner, 1956.

LOCALITY: 1 specimen from A-10–12.

Edwardsii Group

Alpheus crassimanus (Heller), 1865

For synonymy see Banner, 1957.

LOCALITY: 1 specimen from A-1.

DISCUSSION: This single specimen is a female and the identification therefore lacks the confirmation obtainable only by the examination of the small chela of the male; however, on all characteristics it is similar to specimens of the same size from Hawaii (see Banner, 1953: 134).

Alpheus strenuus Dana, 1852

For synonymy see Banner, 1957.

LOCALITY: 2 specimens from A-3.

DISCUSSION: Special efforts were made to collect large specimens, presumably of this species, from the windward reef flat where they were abundant. However, it was found impossible, for they lived in burrows in consolidated coral where a geologist's pick would scarcely penetrate.

The Gilbertese on the island informed me that they used this shrimp—and some other species of small chelate shrimp-like crustaceans that I was unable to collect—as food. The shrimp were caught in the back-ridge trough of the windward reef with nets at night when torch fishing. The collective name for this group of decapods is "Teniwarowaro," and my informant stated that their size ranged to 14 inches long (235 cm.). The Gilbertese ate the cephalothorax and abdomen of the shrimp.

Alpheus pacificus Dana, 1852

For synonymy see Banner, 1956.

LOCALITIES: 1 specimen at A-2, 40 at A-3, 3 at A-6, 1 at A-7.

DISCUSSION: Some of the specimens placed in this species are lacking their small chela, so that they can not be positively identified. However, they agree on other characteristics with the complete specimens.

In this group of specimens slight sexual dimorphism is found in the proportions of the small chela, with the fingers of the male being relatively longer (up to twice as long as the palm) than in the female where they are about 1.5 times as long as the palm. However, the characteristic is not constant, especially for those of smaller size where the finger length is quite variable between these limits.

Alpheus dolerus Banner, 1956

For synonymy see Banner, 1956.

LOCALITY: 2 specimens at GOC-51.

DISCUSSION: The finger of the small chela of the male bears a fringe of setae that reaches about half the length of the dactylus on the inner face and a shorter distance on the outer face; this fringe is similar to the fringe of the "balaeniceps-type" chela except that it is continuous over the superior surface of the finger and the finger is not expanded. Otherwise the two specimens are like those of Saipan.

Alpheus parvirostris Dana, 1852

For synonymy see Banner, 1956.

LOCALITIES: 1 specimen at GOC-22, 3 at GOC-28.

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[3] These are the title page dates, and evidently do not correspond to the actual dates of publication; however, there appears to be some difference of opinion as to the actual dates of publication.

Records of Scattering Layers from New Zealand Seas

B. M. BARY[1]

HITHERTO THE SCATTERING of the ultrasonic pulses of echo sounding equipment attributable to biological agency (Johnson, 1948; Kampa and Boden, 1954*b*) has not been recorded from New Zealand waters. However, Dietz (1948) reported on occurrences, over extensive areas, of the deep scattering layer in the Pacific and Antarctic oceans, and on this ground alone, the presence of scattering in New Zealand waters could be expected. Recent investigations of occurrences and distribution of plankton in New Zealand waters (Bary, in press) suggest an abundant zooplankton, and it would appear also that suitable hydrological conditions for the necessary concentrations of organisms may exist in the disturbed, mixed waters which occur within the New Zealand area. Again, large shoals of pelagic fish are frequently seen in the coastal waters. It is therefore consistent that records are available which show scattering of sound from both plankton and fish.

The notes which follow deal briefly with some of these records from New Zealand. Both deep and shallow scattering layers, multiple layering, and scattering from fish shoals are discussed. One record is believed to show scattering from layers of zooplankton which are associated with a shoal of fish. Other records illustrate two related phenomena, that of separated multiple layers maintaining their identities throughout the ascent to the surface at night, and the converse—the differentiation and subsequent descent of separate layers from the surface at dawn.

ACKNOWLEDGMENT

I am grateful to Mr. J. W. Brodie, Superintendent, New Zealand Oceanographic In-

stitute, for granting access to the collection of fathograms housed at the Institute.

MATERIALS

The hydrographic survey being carried out by H.M.N.Z.S. "Lachlan" is a continuing source of fathograms of coastal and offshore waters. Other naval vessels and coastal and overseas merchant shipping have contributed many records from the high seas. "Lachlan" fathograms are particularly useful for shallow scattering records. The other shipping offers a source for deep scattering records, but in fact, no scattering has been detected in any of the fathograms from these ships. Some of the most useful records have originated in special investigations made in New Zealand waters by R.R.S. "Discovery II," of the National Institute of Oceanography, England, and by the Danish Expedition in H.D.M.S. "Galathea." I am most grateful for permission to reproduce records from both of these sources.

All examples of scattering have been obtained incidental to other requirements. For this reason the records are not always as clear as they might have been had the sounder been tuned to give maximum strength from the scattering layers. It is unfortunate, too, that promising records have been phased out in a number of instances; and additional difficulties are met in the fading of some fathograms made on iodide paper.

SCATTERING LAYER RECORDS

The localities and lineal extent of the records of scattering for the New Zealand area are shown in Figure 1. Figures 2 to 9 reproduce some examples, and a general summary of all occurrences is given in Table 1.

The ascents of the two shallow scattering layers are shown in Figure 2, a trace made

NEW ZEALAND
— showing —

LOCALITIES OF
SCATTERING–LAYER RECORDS

▨▨▨▨······ Scattering Layers.
D 1–4 ···· "Discovery II" Records.
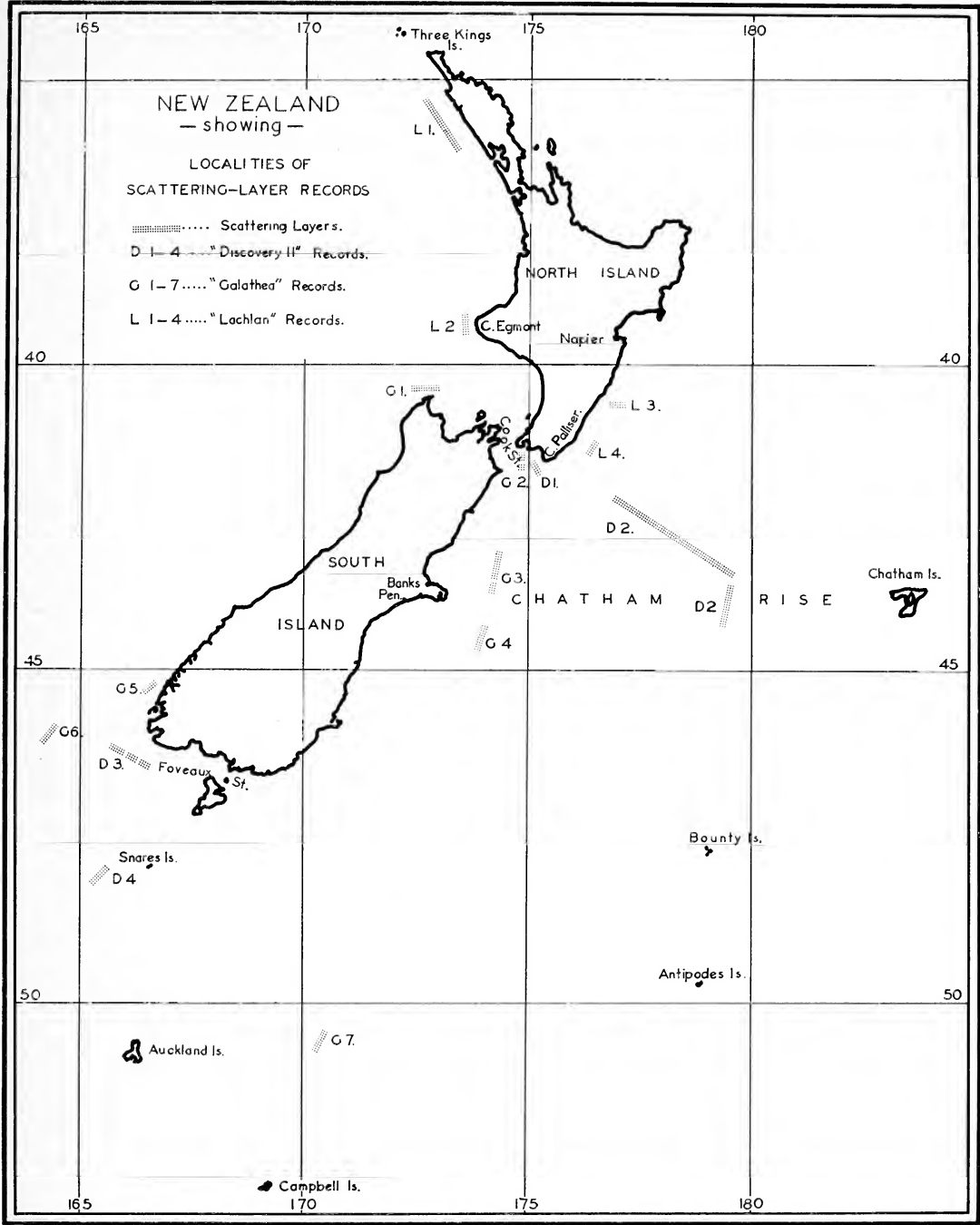G 1–7 ····· "Galathea" Records.
L 1–4 ····· "Lachlan" Records.

FIG. 1. The localities and approximate lineal extent of scattering layer records from New Zealand waters. All available records are shown (and see Table 1), but not all are otherwise referred to in the text.

from "Lachlan" in coastal waters, eastern North Island (L2, in Fig. 1). This is not a strong record, but two separate layers, each of which is broken into parts, are visible ascending between the bottom and the surface. Rate of ascent for both layers is at ap-

TABLE 1

SOME FEATURES OF THE SCATTERING RECORDS FROM NEW ZEALAND SEAS

RECORD NO.	FIG. NO.	SHIP	DATE	TIMES	DEPTH OF WATER, (M.)	NOTES ON LAYER(S)	DEPTH OF SCATTERING, (M.)	RATE OF MOVEMENT, M./MIN.	POSSIBLE NATURE OF ORGANISMS
I.1	..	H.M.N.Z.S. "Lachlan"	11.V.54	2330–2345	530–402	Brief appearance of a single layer in ascent	73	..	Plankton and possibly fish
I.1	..	"	12.V.54	0130–0230	349–256	Double layer, clear of bottom and stationary	Between 109 and 183	..	
L.2	2	"	10–11.V.54	2130–2300	110±	Two widely separated layers ascending between bottom and surface	91–0	1.5	Plankton
L.2	3	"	11.V.54	0645–0800	119–137	Single layer in dawn descent	0–122	2.1 m./min. and 1.3 m./min.	Plankton
L.3	7	"	12.II.54	2135–2235	Approx. 1828	Some multiple layering. Layers descending then ascending in an anomalous manner	91±	..	Plankton
L.4	4	"	23–24.II.54	0430–0500	128–343	Separated, multiple layers, 15 mins. apart, in descent	0–64 0–35	Approx. 2	Plankton and fish shoal?
G.1	..	H.D.M.S. "Galathea"	21.XII.51	0645–0745	110–70	Stationary layers and shoals	Between 50 and 70	..	Plankton and fish
G.2	..	"	27.XII.51	2000–2230	90–600	Layering and shoals, stationary and in ascent	30 m. and 70–200	..	Mixed fish and plankton?
G.3	5	"	27.XII.51	0400–0515	960–530	Separated multiple layers in descent	0–200	1.3 and 0.6	Plankton
G.3	..	"	27.XII.51	0610–0700	570–380	Uneven shoals, lying parallel with the bottom	From 300–200	..	Fish?

TABLE 1—*Continued*

SOME FEATURES OF THE SCATTERING RECORDS FROM NEW ZEALAND SEAS

RECORD NO.	FIG. NO.	SHIP	DATE	TIMES	DEPTH OF WATER, (M.)	NOTES ON LAYER(S)	DEPTH OF SCATTERING, (M.)	RATE OF MOVEMENT, M./MIN.	POSSIBLE NATURE OF ORGANISMS
G4	6	H.D.M.S. "Galathea"	28.XII.51	1100–1244	330–540	Single layer at daylight level	Between 280 and 140	..	Plankton
G5	..	"	13.I.52	1900–2022	4300±	Deep, patchy layer, ascending and descending irregularly	Between 300 and 3000	..	Fish, or sounder fault?
G6	..	"	13.I.52	0915+	200	Short, dense layer lying near to and parallel with the bottom	200+	..	Probably fish
G7	..	"	29–30.XII.51	2400–0100	520	Faint scattering in mid-depths	Between 100 and 200	..	?
D1	..	R.R.S. "Discovery II"	2.XI.50	1630–1715	640–128	Faint to strong scattering at day level. Layer intercepts slope of shelf	238–183	..	Possibly plankton
D2	..	"	3–4.XI.50	0245–0830	519–366	Scattering in the surface waters, during descent, and at daylight level of 183 to 238 m.	Between 0 and 183–238	2.6	Plankton
D2	..	"	4–5.XI.50	0930–1207	311	Scattering stationary at daylight level	183	..	Plankton
D3	8 and 9	"	26.V.51	1650–1720 1845–55 1900–2130	128–338	Mixed shoals and layering. Scattering layers ascending, 2.0 m./min.	186–109	2.0	Plankton and fish
D4	..	"	11.XII.50	1656–1740	354–429	Faint scattering, parallel to, and near, deepening bottom	320–356	..	Fish?
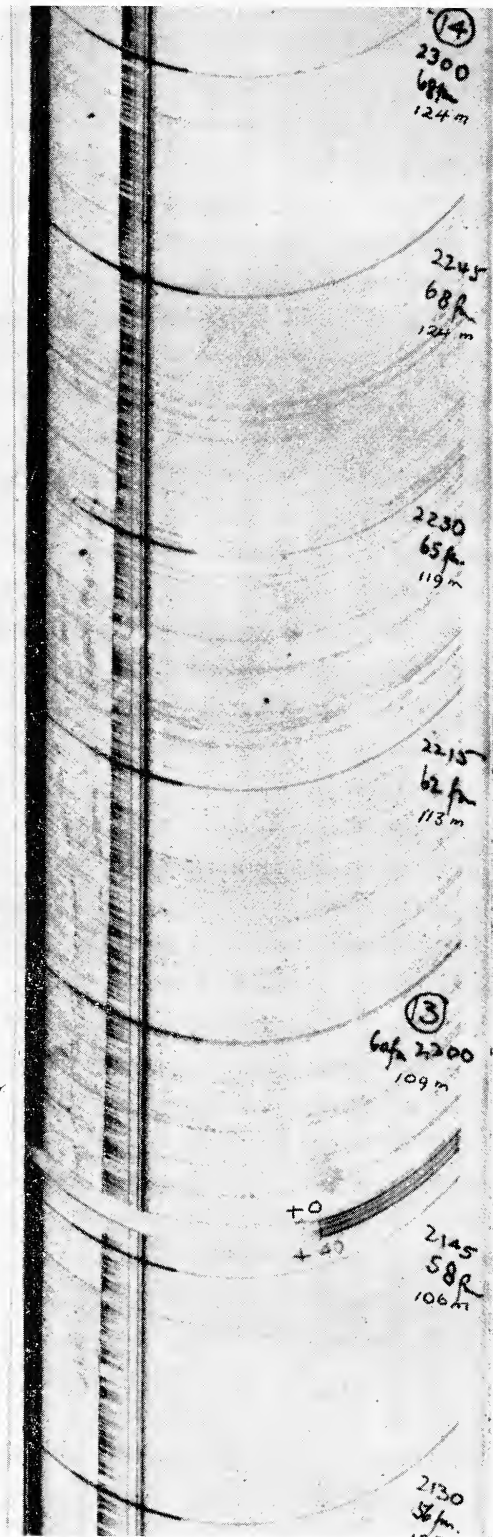
proximately 1.5 m. per minute. The first begins to ascend at about 2130 hours, arriving at the surface around 2240; the second layer begins 15 min. later than the first and arrives at the surface at 2300 hours. Depth of water is between 102 and 124 m. The nighttime concentration of organisms at the surface is masked by the transmission signal. However, marked concentration in depth becomes apparent in the 15 to 20 minutes preceding the dawn descent (Fig. 3. This record is part of that shown in Fig. 2). This single layer begins to descend at 0645 hours. Downward migration is approximately 2.1 m. per min. during the first 30 minutes, but over the next 45 minutes the rate is slower, at approximately 1.3 m. per min. The layer retains its entity for a short while after it has reached the bottom.

Early stages in the descents of two separate layers are illustrated in Figure 4, a "Lachlan" trace from north of Cape Palliser (L4, in Fig. 1). The first layer descends clear of the transmission signal at approximately 0430 hours and after a short descent appears to split into two layers. One of these two appears to join with a second, dense layer which begins to descend about 15 minutes later than the first. Rate of descent is at about 2 m. per min. In a "Galathea" record made over the Chatham Rise and shown in Figure 5 (G3, in Fig. 1), two separate layers, preceded by a dense surface concentration, are shown during the dawn descent. The downward migration commences about 0400 hours and is strongly in evidence by 0500 hours. Both layers appear to split into two. Rates of descent approximate 1.3 and 0.6 m. per min. respectively for the first and second layers. The record rather abruptly fades out at 0515 hours.

A second "Galathea" record, Figure 6, shows a scattering layer at its daytime level. At its deepest the layer is at about 183 m., but its depth varies considerably. This record was made between 1100 and 1230 hours in

FIG. 2. The evening ascent of two separate layers in shallow coastal waters—the southern end of "Lachlan" record, L2, in Figure 1.
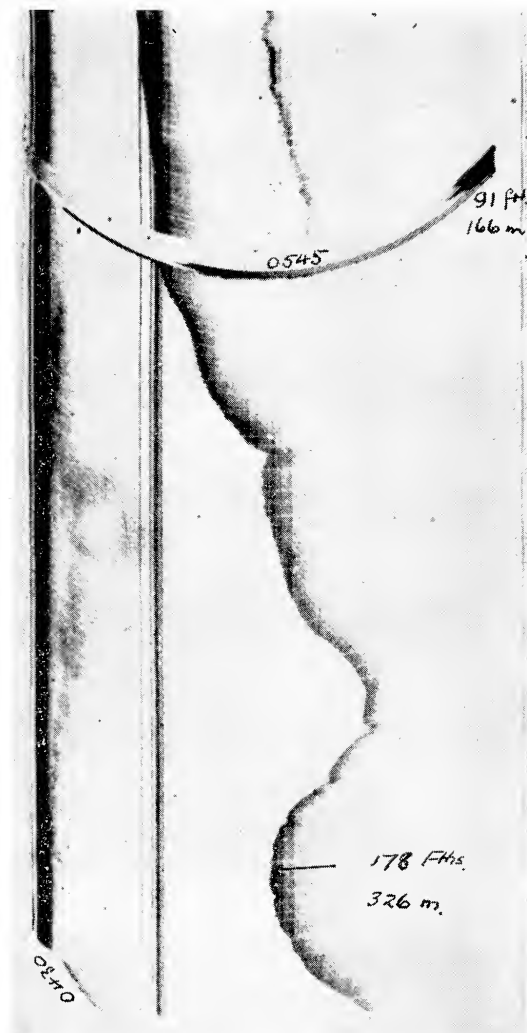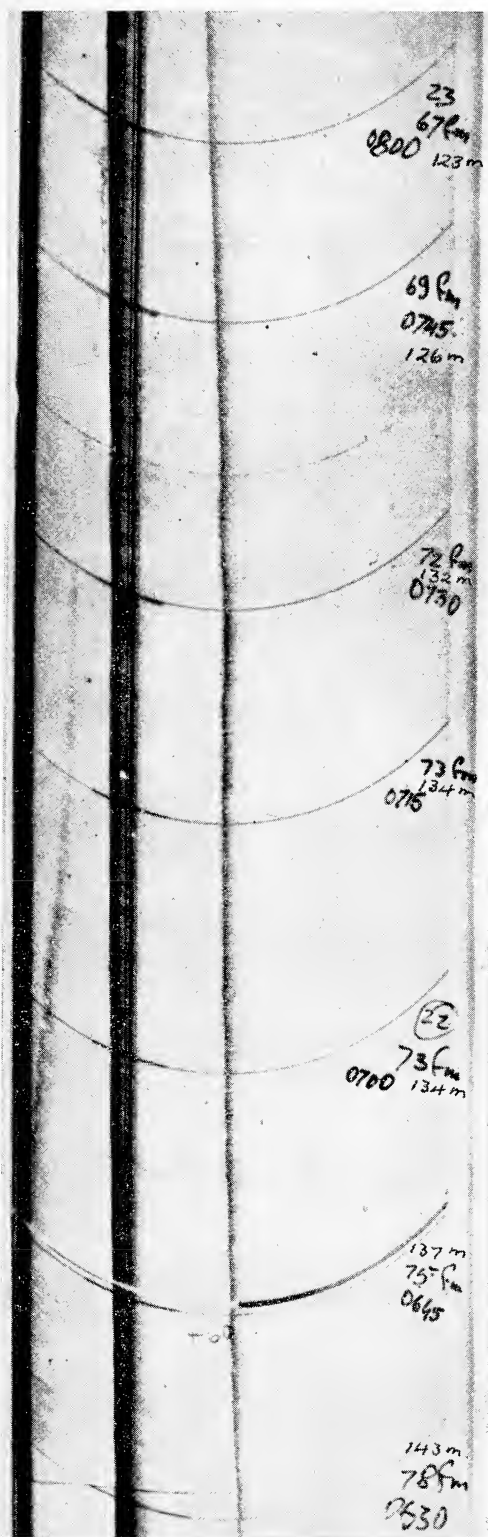
FIG. 4. The dawn descent of two separate layers, the first of which also splits into two; "Lachlan" record, L3.

water of 330 to 550 m. seaward of Banks Peninsula (G4 in Fig. 1).

Examples of more or less anomalous behaviour of layers are shown in Figures 7 and 8. Figure 7 is from a "Lachlan" fathogram made south of Napier (L3, in Fig. 1). It illustrates a scattering layer which is descending to a deeper level between 2135 and 2155 hours at which depth it becomes stationary

FIG. 3. The dawn descent. Note the concentration of organisms in depth prior to the differentiation and descent of the layer; the northern end of "Lachlan" record, L2.

for 15 minutes (around 2200 hours), and then rises slowly. Sunset was at 1930 hours (mid-February, 1954) and darkness would have fallen about an hour before this trace was commenced. The trace is of even texture with a suggestion of subsidiary layers within the main one; it is probably the result of scattering from zooplankton. If so, the record illustrates a curious reversal in the expected direction of movement of the organisms. It is possible that this special reaction is an effect of moonlight. The moon was in the first quarter and crossed the meridian at about 2130 hours on the day in question.

A "Discovery II" record (Fig. 8) made when approaching Foveaux Strait from the west (D3, in Fig. 1) is of strongly developed scattering most of which is remaining at depth. Sunset was at 1700 hours (May 1951), there was no moon, and it would have been dark for some time before 1950 hours when the record begins. The unevenly distributed, dense patches in this trace suggest that fish may have been the chief cause of the scattering. Fish do not necessarily perform diurnal migrations, and thus the fact that the main body of the scattering organisms is not ascending might be explained. On the other hand, three or four distinct layers can be detected in the earlier (left-hand) one-fifth of the record. These penetrate the fish scattering and are ascending towards the surface at rates of 2.0 to 2.5 m. per min. Their appearance is suggestive of scattering from planktonic organisms. This record may be indicative therefore of fish following and feeding on concentrations of plankton which are undergoing normal vertical migration.

Some other records are available, believed to be of scattering from fish shoals. Figure 9 illustrates one such record, made in the western approaches to Foveaux Strait by "Discovery II," earlier on the same day as that

FIG. 5. The dawn descents of separated layers followed by splitting of each of the layers. The heavier trace in the second layer is suggestive of larger animals being present; "Galathea" record, G3.

FIG. 7. Anomalous behaviour of a scattering layer during darkness. At first it is descending deeper into the water, and then begins to rise again. The phasing of the sounder has displaced the transmission signal down the fathogram; "Lachlan" record, L3.

shown in Figure 8. The dense shoal (marked "Fish?") would appear from its uneven denseness and patchiness, to be a large fish shoal, which then extends at lesser concentrations more or less parallel to the bottom. In view of the subsequent history of this zone of scattering—the record is continuous with that in Figure 8—it is possible that other pelagic organisms are contributing to it as well.

FIG. 6. A scattering layer maintaining a fluctuating daylight level in moderately deep water over the Chatham Rise; "Galathea" record, G4.

DISCUSSION

Investigations of sound scattering of biological origin are being pursued for their bearing on studies of animal behaviour, distribution and ecology (Hersey and Moore, 1949; Moore, 1950), physiology (Kampa and Boden, 1954*a;* 1954*b*) and on fisheries biology (Richardson, 1952; Haffner, 1952). Not all of the physical characteristics of those invertebrate organisms which cause scattering are understood as yet (Smith, 1951, 1954), but the air bladder in certain fish is regarded as an excellent scatterer of sound (Marshall, 1951; Hersey and Backus, 1954). The principles emerging from investigations into these various aspects of the subject may be generally applicable, but such principles are only to be derived from specific, detailed observations from many different localities.

Scattering layer development may vary from one area to another. Some of the variation is attributable to the distributions of the different organisms which are able to effect the scattering. Moore (1950) has discussed such variations in scattering in relation to the distributions of several species of euphausiids in the north Atlantic. On the other hand, strong development of layers could result from those high concentrations of animals which may be associated with areas in which intermixing of contiguous bodies of water of differing properties is taking place. Thus localised scattering might well occur in the upwelling waters believed to be present at several localities about New Zealand (Garner, 1953). On a larger scale, scattering could be associated with the —possible—extensive disruption of the water layering and the resultant mixing of the waters where north-south moving masses cross the Chatham Rise (Fig. 1). This topographic barrier to unrestricted flow rises from about 2800 m. to within 450 m. of the surface and lies

FIG. 8. Probable fish records combined with layers of plankton (on the left of the record). The latter are visible as three or four ascending layers cutting through the dense fish record; "Discovery II" record, D3.
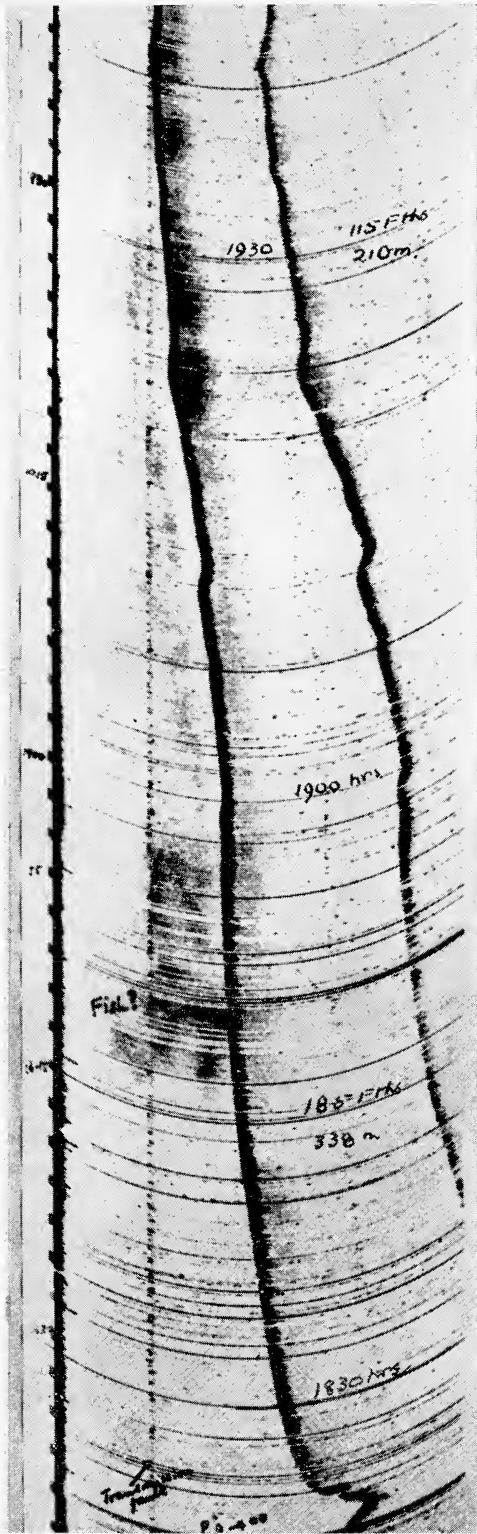
athwart the direction of movement of the water masses. Relevant to these points, it is of interest to note that the present examples of scattering are predominantly from two areas where mixed waters are believed to be present. One of these is to eastward of South Island, and is associated with the supposed area of disturbed water from the Chatham Rise obstruction. Moreover, the subtropical convergence migrates seasonally across this area, although its relationship to present examples of scattering is not known. The second area, in the south west of South Island, is believed to be associated with mixing between waters of subantarctic and subtropical origins (Deacon, 1937).

The records presented from New Zealand waters appear to be similar in essentials to those made elsewhere. Their chief value lies in showing that development of scattering is fairly widespread in the area. Two features are noteworthy. Several records have illustrated the successive descents from the surface of two or more separate layers, and conversely, the ascents up to the surface of distinct layers. Development of multiple layering during the descent or ascent of a layer has frequently been recorded, but the writer is unaware of any published records in which such a separation into layers persists up to the surface, or develops at the surface prior to the descent of the organisms.

The second feature is illustrated in Figure 8. It is a matter for frequent conjecture whether scattering is caused by planktonic animals, notably euphausiids (Boden, 1950; Moore, 1950), or whether it is caused by predatory fish accompanying and feeding on planktonic organisms which are undergoing vertical migration (Hersey & Moore, 1949). In Figure 8, the large, dense masses of scattering have the appearance of fish shoals. Also, the distinct layers, present in the left-hand mass, are strongly suggestive of scatter-

FIG. 9. Probable fish record made earlier in the day than that in Figure 8; "Discovery II" record, D3.

ing of planktonic origin. If the two types of scattering have been caused by fish and plankton as is suggested, this is a record of fish which are associated with ascending planktonic concentrations.

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NOTES

An Unusually Large Salp

A large example of *Thetys vagina* Tilesius, solitary form, was captured in a 1-meter (mouth diameter) closing-type plankton net at a depth between 120 and 170 meters by the Pacific Oceanic Fishery Investigations, U. S. Fish and Wildlife Service, on February 5, 1956, at 22° 15′N. latitude, 157°46′W. longitude. The specimen measured 306 mm. in length without processes and 333 mm. with processes. By water displacement its total volume equalled 278 ml.

This specimen is apparently larger than any salp previously known and is therefore considered worthy of note. The largest salps previously reported have had lengths as follows: *Thetys vagina*, solitary form, 226 mm. (Traustedt, 1885. *K. Danske Vidensk. Selsk., Skr., Naturv. og. Math. Afd.* 2(8): 337–400 [as *Salpa costata-tilesii*]); *Helicosalpa komaii* (Ihle and Ihle-Landenberg), solitary form, 230 mm. (Komai, 1932. *Kyoto Univ., Col. Sci., Mem.*, Ser. B. 8(1): 65 80 [as *Salpa virgula*]); *Salpa maxima* Forskål, solitary form, 230 mm. (Thompson, 1948. *Pelagic Tunicates of Australia.* Commenwealth Council for Scientific and Industrial Research, Melbourne. 196 pp.). In volume the largest specimen previously reported was a solitary form of *Helicosalpa virgula* (Vogt), 141 mm. in length, which measured 158 ml. in total volume by water displacement (Yount, 1954. *Pacific Sci.* 8(3): 276–330).

The nomenclature used in this note follows that of Yount (*ibid.*).—*Eugene L. Nakamura, Pacific Oceanic Fishery Investigations, U. S. Fish and Wildlife Service, Honolulu, Hawaii, and James L. Yount, Dept. of Biology, University of Florida, Gainesville, Florida.*

First Pacific Record of the Whale-louse Genus *Syncyamus* (Amphipoda: Cyamidae)[1]

The genus *Syncyamus* is known only from the central Gulf of Mexico, where it was taken from the surface of a false killer whale, *Pseudorca crassidens* (Owen) (Bowman, *Mar. Sci. Gulf and Caribbean Bul.* 5(4): 315–320). Recently a number of cyamids were collected from the blowhole and angle of the jaw of a dolphin which was shot in Panama Bay, 2 miles southeast of Tabogvilla Island. Mr. Franklin Sogandares-Bernal, Department of Zoology, University of Nebraska, who collected the cyamids, kindly forwarded them to the U. S. National Museum, where they have received catalogue number 99588.

Examination showed the cyamids to be members of the genus *Syncyamus*, differing only slightly from type specimens of *S. pseudorcae* Bowman. The Panama Bay specimens are smaller (length of largest ovigerous female, 3.0 mm.); the anterolateral margins of pereion somite 2 are more pointed, with the inner members of the produced double lobes longer than the outer; and pereion somites 6 and 7 are not coalesced dorsally, but separated by a distinct suture. The mouth parts are nearly identical with those of the Gulf specimens. With the limited material at hand, I am unable to determine whether the Panama Bay specimens should be separated specifically from *S. pseudorcae*.

The skull of the dolphin was badly damaged and was not preserved. Fortunately, Mr. Sogandares-Bernal made a color photograph of the dolphin, from which Dr. David H. Johnson, Curator, Division of Mammals, U. S. National Museum, has tentatively identified it as a young specimen of the long-snouted dolphin, *Stenella graffmani* (Lönnberg) a common dolphin in Panama Bay.

The present record is of interest not only because it is the second one for *Syncyamus* and

the first Pacific record for this genus, but, insofar as I have been able to determine, because there are only five other published cases of cyamids infesting the small, toothed cetaceans commonly referred to as dolphins and porpoises. In four of these cases the cyamid involved was *Isocyamus delphinii* (Guérin-Meneville) and in three instances the hosts were unidentified dolphins (Guérin-Meneville, *Iconographie du règne animal*, II, pl. 28, fig. 5, 1836; Barnard, *Discovery Rpts.* 5:314, 1932). In one case the host was *Delphinus delphis* (L.) (Lütken, *K. Danske Vidensk. Selsk.* 10: 433, 1873). The other example is that of *Cyamus chelipes* Costa (*Mus. Zool. Univ. Napoli, Ann.* 3: 82, pl. 4, fig. 2, 1863), which was taken from an unnamed dolphin. Although Costa's figures are schematic, it is obvious from them that his species belongs in the genus *Syncyamus*. It is impossible to tell from Costa's account whether *chelipes* is conspecific with the Gulf of Mexico and Panama Bay specimens.

It is evident that additional collections of cyamids from porpoises and dolphins are needed for basic taxonomic studies, and those who have the opportunity to make such collections can greatly aid in filling in the gaps in our knowledge of these interesting amphipods.—*Thomas E. Bowman, Division of Marine Invertebrates, U. S. National Museum, Washington, D. C.*

Brighamia citrina (C. N. Forbes & Lydgate) St. John, comb. nov.

B. insignis Gray forma *citrina* C. N. Forbes & Lydgate, B. P. Bishop Mus., Occas. Papers 6 (4): 11(203), 1917. This plant in the Lobeliaceae, known only from the Haupu Range, Kauai, differs constantly from the only other species, *B. insignis*, by having the corollas lemon yellow, the calyx lobes 0.8–1 mm. long, and the seeds conspicuously papillose. It is judged to be worthy of specific rank.—*Harold St. John, University of Hawaii, Honolulu, Hawaii.*

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CRAWFORD, DAVID L. 1920*a.* New or interesting Psyllidae of the Pacific Coast (Homop.). *Ent. News* 31 (1): 12–14.

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ROCK, JOSEPH F. 1916. The sandalwoods of Hawaii; a revision of the Hawaiian species of the genus *Santalum. Hawaii Bd. Commrs. Agr. and Forestry, Div. Forestry Bot., Bul.* 3: 1–43, 13 pls.

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U P H

PACIFIC SCIENCE

A QUARTERLY DEVOTED TO THE BIOLOGICAL
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UNIVERSITY OF HAWAII PRESS

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Notice of Correction

In the April 1958 issue, Volume XII, No. 2, on pages 177 and 178 in the paper by B. M. Bary, entitled, Records of Scattering Layers from New Zealand Seas, cuts for Figures 6 and 8 are transposed.

Please correct your copy of the Journal by changing Fig. 6 to 8, and Fig. 8 to 6.

PACIFIC SCIENCE

A QUARTERLY DEVOTED TO THE BIOLOGICAL AND PHYSICAL SCIENCES OF THE PACIFIC REGION

Previous issue published April 14, 1958

CONTENTS

The *Plecia* of the Pacific and Southeast Asia
(Bibionidae–Diptera) [1]

D. Elmo Hardy [2]

IN THE PACIFIC REGION the family Bibionidae is almost restricted to the southwest portion of the hemisphere (Melanesia, Australia, and Malaysia) and—except for one species (*Plecia palauensis* Hardy) from the eastern Caroline Islands—the group is completely lacking in all of Micronesia and Polynesia. Beyond a line drawn north and east of the Philippine Islands, New Guinea, Solomon Islands, and New Caledonia, bibionids become rather abundant, especially species of the genus *Plecia*. The species of the southwest Pacific show relationships with those of Indonesia and Malaya and southeast Asia. The present study includes Ceylon, Burma, Thailand, Indochina, and Malaya as well as the Pacific region. Forty-six species and one subspecies are now known from this portion of the world.

I have accumulated these data over a period of many years and have studied all of the available specimens from these areas. I am much indebted to the following entomologists for the loan of material from various institutions: Dr. M. A. Lieftinck and Dr. H. Boschma, Rijksmuseum van Natuurlijke Historie, Leiden, Holland; Dr. A. M. R. Wegner, Museum Zoologicum Bogoriense, Bogor, Indonesia; Dr. G. Kruseman, Zoologisch Museum, Amsterdam; Paul Freeman, British Museum (Natural History), London; Dr. J. L. Gressitt, Bernice P. Bishop Museum, Honolulu, Hawaii; Dr. Alan Stone, U. S. National Museum; Dr. Max Beier, Naturhistorisches Museum, Wien; and Dr. Delfa Guiglia, Museo Civico de Storia Naturale, Genoa.

KEY TO PLECIA OF THE PACIFIC REGION AND SOUTHEAST ASIA, BASED UPON MALES

1. Ocelli present, situated on a raised triangle.............**Plecia (Plecia) 2**

   Ocelli and ocellar triangle lacking. Eyes of male joined on the front up to the top of the vertex. (New Guinea)..........
   Plecia (Heteroplecia) visenda Hardy

2. Thorax dark brown to black..........3

   Thorax usually predominantly rufous, in a few species the mesonotum is discolored brownish red but the furrows and sides are rufous...................15

3. Ninth tergum gently concave on hind margin, not cleft over one-third the length of the segment (Fig. 10*c*)......4

   Ninth tergum deeply cleft, the concavity extending nearly to the base of segment **5**

4. Claspers bilobed, posterior median margin of ninth sternum without a sclerotized lobe (Fig. 10*a*). (Australia)......
   ....**erebea** Skuse

   Claspers simple, posterior median margin of ninth sternum with a sharp-pointed lobe (Fig. 26*a*). (Java).**tenebrosa** n.sp.

5. Sides of mesonotum and scutellum dull red. Mesonotum with three black vittae or with front and median portions black
  6

   Thorax entirely black..............7

6. Claspers well developed, extending well beyond apices of ninth sternum. Lobes of ninth tergum converging and each with a strong apical spine (Fig. 17*a*). (New Guinea)...........**magnispina** n.sp.

   Claspers minute, lobes of sternum strongly developed, lobes of tergum diverging, not bearing an apical spine (Fig. 24). (Ceylon)..........**rufilatera** Edwards

7. Posterior lateral margins of ninth sternum strongly lobate, the apices extend well beyond tips of claspers and near or beyond apices of ninth tergum.......8

   Ninth sternum rounded on posterior lateral margins, the slightly developed lobes do not extend over half the length of the claspers or the lobes of the ninth tergum. (Java)...............**morosa** Edwards

8. Ninth sternum produced into a broad, flat-topped, heavily sclerotized lobe protruding from the median margin. (Phillippine Islands)...........**cana** Hardy

   Ninth sternum not developed as above.9

9. Ninth tergum expanded laterally, from lateral view it is equal or wider than sternum so that from side view the genitalia are wider than long (Fig. 7*b*). Ninth tergum divided into two plates by a very deep cleft, the plates are joined at bases only by a narrow sclerotized line; sides of cleft straight or slightly expanded in middle..........................**10**

   Ninth tergum not expanded laterally, about one-half as wide as sternum and genitalia much longer than wide (in lateral view). Cleft of tergum not so deep and **V**- or **U**-shaped **11**

10. Lobes of ninth sternum comparatively broad, rounded at apices, serrated on inner apices, over two times wider than claspers (Fig. 7*a*). (Netherlands New Guinea) .... **disjuncta** n.sp.

    Lobes of sternum slender, slightly curved and pointed at apices; beyond middle they are not as wide as the claspers (Fig. 19*d*). (Northeast New Guinea)........ ....**monticola** n.sp.

11. Claspers small, rounded at apices, with a sharp-pointed subapical lobe on inner margin. Claspers extending scarcely one-third as far as lateral lobes of sternum (Fig. 14*a*). (Borneo).**fumidula** Edwards

    Claspers of moderate size, not so shaped and extending nearly as far as lobes of sternum.........................**12**

12. Claspers blunt and rounded at apex as seen from a direct ventral view (Fig. 29*a*). From a lateral view a pair of dorsally projected lobes are developed. Mesonotum subshining in the furrows. (Java) ....**tristis** van der Wulp

    Claspers not as above, with no secondary lobes on dorsal surface. Mesonotum entirely opaque.....................**13**

13. Claspers rounded or subacute at apices **14**
    Claspers square tipped. (Borneo)...... ....**fumida** Edwards

14. Claspers strongly curved, with a capitate rounded apical lobe and the basal portion slightly hollowed out and expanded laterally. Sternum with a pair of moderately large submedian lobes. Antennae 9-segmented. (Indonesia)....**furva** Hardy

    Claspers subacute, not capitate, basal portion not hollowed out and with inner basal margins joined by a narrow sclerotized bridge. Ninth sternum without submedian lobes. Antenna 8-segmented. (Caroline Islands)... **palauensis** Hardy

15. Thorax dull red with 3 brownish red vittae extending down mesonotum. Pleura discolored with brown on upper portion. **16**

    At least mesonotum bright orange to rufous, sometimes with a brown to black spot on front margin..............**17**

16. Lobes of ninth tergum ending in a strong apical spine. Posterior lateral margins of ninth sternum developed into slender lobes (Fig. 17*a*). (New Guinea) . . . .
. . . .**magnispina** n.sp.

Lobes of tergum not bearing an apical spine. Posterior lateral margins of sternum not developed as above (Fig. 5). (New Guinea) . . . .**decora** Hardy

17. Thorax all rufous (except for a brown to black spot on upper portion of pleura in *sundaensis* Hardy) **18**

Pleura predominantly brown to black . **35**

18. Ninth tergum and sternum fused on the sides and forming a capsule around the internal genital structures. The claspers and the structure of the sternum cannot be seen except in end view (Fig. 22*a*). (Philippine Islands) . . . .**parva** Malloch

Genital sclerites not fused. Claspers and other structures exposed **19**

19. Ninth tergum not strongly produced at apices, not extending beyond sternum or tips of claspers **20**

Ninth tergum strongly lobate, extending two times the length of sternum (Fig. 11*b*). (Indonesia, Indian Ocean) (some specimens may run here) . . . .
. . . .**forcipata** Osten Sacken

20. Ninth tergum gently concave on hind margin, the concavity extending not over one-half to base of segment (Fig. 16*c*). (Java) . . . .**lieftincki** n.sp.

Ninth tergum deeply cleft, nearly to base of segment **21**

21. Ninth sternum with a pair of submedian sharp-pointed lobes, equal in length to remainder of sternum (measured on a median line) and extending nearly to apices of claspers. Also a narrow-pointed median lobe present (Fig. 28*b*). Lateral

margins of sternum not produced. (Wetter Island, Indonesia) . . . .**tridens** n.sp.

Not as above **22**

22. Lateral lobes on hind margin of sternum narrow, strongly curved inward; median portion with a cleft which is expanded basally (Fig. 30*b*). (Malaya) . . . .
. . . .**varians** Edwards

Lateral lobes not curved as above and sometimes with a slightly expanded median cleft only in *subvarians* Walker.
. . . .**23**

23. Ninth sternum very broad and narrow, at least two times broader than long. Claspers joined at bases, equal in length or longer than ninth sternum, measured through median portion of sternum . . **24**

Ninth sternum as long as wide. Claspers much shorter than sternum **26**

24. Claspers blunt, broadly rounded at apices (Fig. 8*b*). (Ceylon and India) . . . .
dispersa n. name (for *thoracica* Guérin)

Claspers narrowed apically **25**

25. Posterior lateral margins of ninth sternum produced into pointed lobes. Posterior lateral margins of ninth tergum produced. Ocellar triangle tiny in male, the entire triangle is equal to only 3–4 eye facets. (East Indies) . .**javensis** Edwards

Posterior lateral margins of ninth sternum and ninth tergum not so produced (Fig. 1*a*, *c*). Ocellar triangle normal, each lateral facet equal to about 3 compound eye facets in length. (Australia, New Hebrides, Papua, Solomon Islands) . . . .
. . . .**amplipennis** Skuse

26. Lobes on posterior lateral margins of sternum slender stemmed, enlarged at apices. (Philippine Islands) . . . .
. . . .**mayoensis** Hardy

Lobes of sternum not capitate **27**

27. Ninth sternum with a pair of closely placed lobes at middle of hind margin, separated by a narrow V-shaped cleft. Posterior lateral margins of sternum not lobate.........................28

    If ninth sternum has median or submedian lobes on hind margin they are well spaced by a broad U-shaped cleft. Posterior lateral margins strongly lobate. 29

28. Median lobes of sternum very strong, claspers not visible from a ventral view (Fig. 2a). Ninth tergum with a broad U-shaped cleft (Fig. 2c). (Aru Islands)... ....aruensis Edwards

    Median lobes comparatively small, claspers extending strongly beyond hind margin of sternum (Fig. 3a). Ninth tergum with a narrow V-shaped cleft (Fig. 3b): (Philippine Islands)....bakeri Malloch

29. Claspers tiny, inconspicuous, and partly or completely fused with ninth sternum. Median portion of hind margin of ninth sternum produced into a broad heavily sclerotized capitate projection, either truncate at apex or terminating in a pair of blunt lobes and extending beyond apices of lateral lobes of sternum...30

    Claspers well developed, distinctly articulated with the sternum. No such development of a median lobe.......31

30. Median process of sternum truncate at apex. (Philippine Islands)............. ....zamboanga Hardy

    Median process developed into a pair of blunt lobes at apex (Fig. 13b). (Sumatra, Philippine Islands)................ ....fulvicollis (Fabricius)

31. Ninth sternum with a median moundlike lobe on hind margin...............32

    No median lobe on sternum........33

32. Lobes on posterior lateral margins of ninth sternum rounded at apices, separated at bases by the width of the lobe at this point. No submedian lobes on sternum. Claspers truncate, pointed at outer apices (Fig. 21a). (Australia)......... ....ornaticornis Skuse

    Lateral lobes rather slender pointed, widely spaced, separated by four times their width at base; a pair of small submedian lobes present on hind margin. Claspers rounded at apices (Fig. 23). (Kei Island, Indonesia).............. ....ruficornis Edwards

33. Lateral lobes of sternum slender and elongate, extending about two times the length of claspers and more than two times longer than the submedian lobes on hind margin...................34

    Lateral lobes tapered to a point, extending scarcely beyond apices of claspers and submedian lobes. (Indonesia)..... ....sundaensis Hardy

34. Ninth sternum extending well beyond apices of tergum, so tergum is not plainly visible from direct ventral view. The submedian lobes of sternum rounded. Cleft in middle of hind margin of tergum narrow, about one-sixth the width of tergum and extending only two-thirds the length of segment on the middle line; the lobes of the tergum are rather quadrate. (Siam).........siamensis Hardy

    Ninth tergum extending almost to apices of sternum. Submedian lobes of sternum with a subapical point on outer side (Fig. 25b). Cleft of tergum broadly V-shaped about one-third as wide as tergum and nearly bisecting segment (Fig. 25a). (Indonesia)...subvarians Walker

35. Posterior margin of ninth sternum with a pair of elongate submedian rodlike lobes 36

    No such rod-shaped lobes.........37

36. Lobes of ninth tergum widely divergent at apices. The claspers extend well beyond apices of lobes on hind margin of sternum. Both lobes on posterior margin of sternum about equal in size, neither is one-half as long as clasper. (Bougainville, Solomon Islands).**gurneyi** Hardy

Lobes of ninth tergum not divergent. Claspers not extending to apices of rod-like lobes. Upper lobe on each side of sternum as long as clasper. (Solomon Islands)..............**laffooni** Hardy

37. Ninth sternum with a large semimembranous extension on hind margin (posterior median portion), this is longer than the remainder of segment and two-thirds as long as claspers. A very strong pair of accessory aedeagal structures extend well beyond claspers. Posterior lateral margins of sternum with a pair of small lobes. (Solomon Islands).......
.......................**manni** Hardy

Not as above....................38

38. Either the ninth sternum or tergum forcipate or produced at apices into slender pointed lobes, about equal in length to remainder of segment and often curved inwardly........................39

Ninth sternum or tergum without forcipate lobes; lobes not one-half the length of segment and tergum rounded at apices
................................44

39. Ninth tergum forcipate, sternum not.40

Ninth sternum forcipate, tergum not.42

40. Front portion of mesonotum with a large black spot in middle. Posterior lateral margins of ninth sternum produced into pointed lobes (Fig. 4*a*). (Burma)......
....................**burmensis** n.sp.

Mesonotum entirely rufous. Posterior lateral margins of sternum not produced
................................41

41. Claspers terminating in a slender spine-like lobe on inner apex. Posterior median margin of sternum developed into a lobe which extends beyond posterior lateral margins of segment (Fig. 12*a*). (Malay Peninsula).........**forficula** Edwards

Claspers obliquely truncate at apices; no such lobe. No median lobe developed on sternum (Fig. 11*b*). (Indonesia).......
..............**forcipata** Osten Sacken

42. No submedian lobes on hind margin of ninth sternum. Claspers pointed on outer apices (Fig. 18*a*). Ninth tergum nearly quadrate in shape, truncate at apices (Fig. 18*b*). (Peninsular Siam).........
..................**malayaensis** Hardy

Narrow submedian lobes present along sides of each clasper, claspers not pointed on inner side (Fig. 14*a*). Ninth tergum subacutely pointed at apices........43

43. Each clasper produced into a sharp pointed beaklike subapical lobe on inner side (Fig. 14*a*). (New Britain).........
.........**fumidula diversa** n. sub. sp.

Claspers rather triangular, without a beaklike point (Fig. 15*a*). (New Guinea)...
..................**inconspicua** Hardy

44. Ninth sternum with two or three well-developed lobes on posterior median margin. No lateral lobes...........45

Ninth sternum without conspicuous median lobes........................46

45. Ninth sternum with a pair of lobes on posterior median margin separated by a **U**-shaped concavity, these extend beyond apices of claspers. (Borneo)......
..................**borneensis** Edwards

Ninth sternum with a pair of rather small lobes, not extending half as long as claspers; a large flat-topped projection separates the two lobes. Claspers dentate apically (Fig. 6*a*). (Australia, Tasmania)
..................**dimidiata** Macquart

46. Ninth sternum but slightly broader than long, hind margin not noticeably concave and with a pair of tiny median lobes. (Buru Island)......**buruensis** Edwards

    Ninth sternum much wider than long, concave on hind margin and with no lobes in middle..................47

47. Posterior lateral margins of ninth sternum drawn to a sharp point (Fig. 27*a*). Claspers, seen in end view, bilobed at apex (Fig. 27*b*). (Sumatra, Java)....... ....**tergorata** Rondani

    Ninth sternum rounded on posterior lateral margins. Claspers not bilobed...48

48. Claspers acutely pointed at apices. Aedeagus with well-developed rodlike accessory structures extending to tips of claspers, these have two additional basal lobes (Fig. 9*a*). (Malaya, Borneo)..... ....**dubia** Edwards

    Claspers rounded at apices. Accessory structure not so developed. (Java).... ....**tjibodensis** Edwards

Plecia amplipennis Skuse
Fig. 1*a–c*

Plecia amplipennis Skuse, 1888, Linn. Soc. N. S. Wales, Proc. (2)3: 1372.

Skuse later (1891, Linn. Soc. N. S. Wales, Proc. (2)5: 635) considered *P. amplipennis* as a synonym of *P. fulvicollis* Fabricius, but I believe it is quite obvious that he was wrong. *P. amplipennis* agrees with *fulvicollis* only in having the thorax entirely rufous. The male genitalia are distinctly different, refer to Figures 1*a* and 13*b*. The broad rounded lobes of the ninth tergum are very densely black haired (Fig. 1*c*). The clasping structures are acutely pointed at apices and are joined together at bases by a sclerotized bridge. The ninth sternum is two times broader than long and the aedeagus has a pair of rodlike accessory structures (Fig. 1*a*).

The female specimens are very similar to those of *fulvicollis* Fabricius and *aruensis* Edwards except that the antennae are entirely dark brown to black. The female antennae are 11-segmented. The front has a prominent longitudinal ridge extending from the ocelli to antennae, this is entirely black; in *aruensis* the lower part is yellowish.

Length: Body, 6.0–8.5 mm.; wings, 7.0–9.5 mm.

The species was described from Queensland, Australia. I have studied specimens from numerous localities in Queensland, New Hebrides, Java, Papua, New Guinea, and the Solomon Islands. The specimens from areas outside of Queensland have been just slightly smaller and the claspers of the male are not so slenderly pointed as in the typical form (Fig. 1*a, b*). This was also pointed out by Hennig (1940, Arb. über Morph. u. Taxonom.
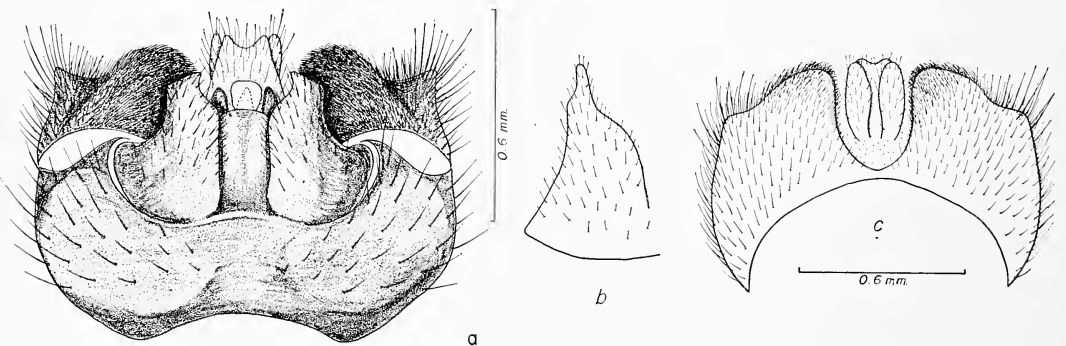
FIG. 1. *Plecia amplipennis* Skuse. *a*, Genitalia, ventral view; *b*, left clasper of typical *amplipennis*; *c*, ninth tergum.

Ent. 7:254, Figs. 21, 22). Some variation has also been seen in the shape of the ninth tergum.

Type in the Macleay Museum, Sydney.

Plecia aruensis Edwards
Fig. 2a–c

Plecia aruensis Edwards, 1925, Treubia 6(2): 159.

This species belongs in the *fulvicollis* group by having the thorax entirely opaque orange. It is distinguished from all known species by the presence of a pair of large median lobes at the apex of the ninth sternum of the males and by the unusual development of the claspers.

MALE: Antennae 10-segmented, the apical one, however, is very small and inconspicuous. The scape and pedicel are yellow, the remainder of the antennae brown to black. Ocellar tubercle very well developed. Thorax entirely opaque orange, except for a very narrow brownish vitta down middle of scutellum. Thorax devoid of pile except for a few pale hairs on the sternopleura. Halteres dark brown to black, with pale bases. Legs all black and densely black pilose, all segments slender. Wings rather dark brownish fumose, stigma scarcely differentiated from the wing membrane. Vein R_{2+3} straight and forming about a 70° angle with R_{4+5}. Costa extending nearly one-half the distance between the tips of R_{4+5} and M_1. Cubital cell widely open in the wing margin but the cubital vein is bent down rather sharply at its apex. Abdomen black, densely black pilose, about equal in length to the head and thorax combined. Genitalia very densely covered with long black pile. Ninth tergum cleft nearly to its base on the hind margin (Fig. 2c). The ninth sternum is developed into a pair of strong apical lobes which are separated by a V-shaped concavity (Fig. 2a). Each of these lobes is partially developed into two lobes at its apex and each has a small inconspicuous ventral lobe on the dorsal surface. The dististyli are very unusual and apparently not functional as claspers.
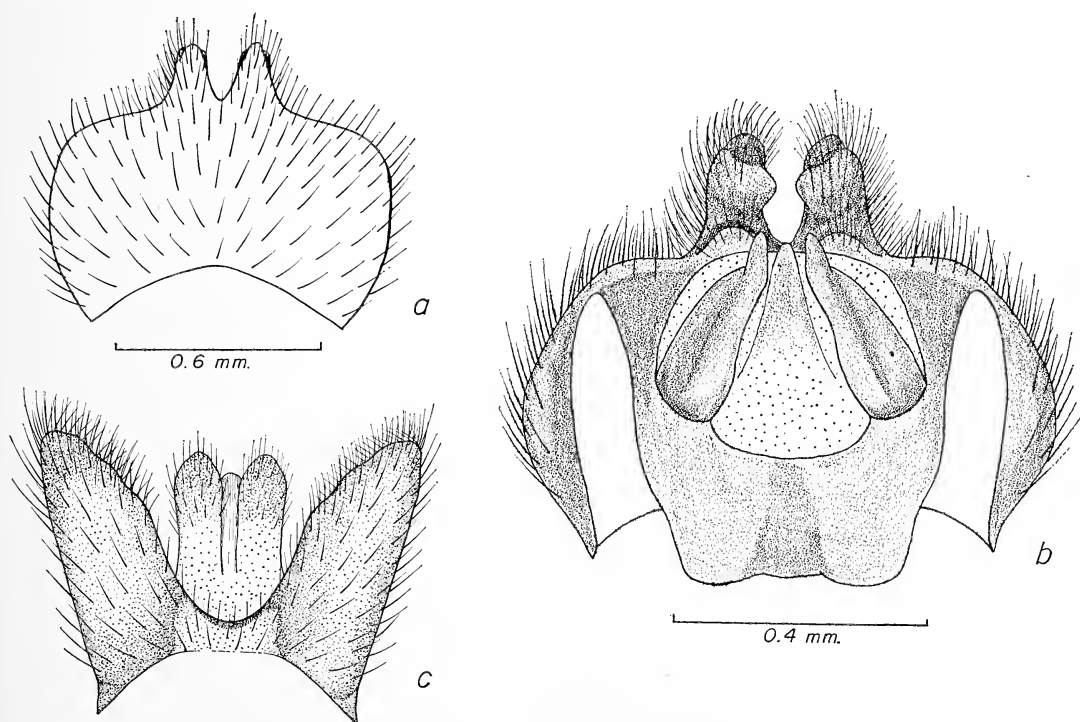
FIG. 2. *Plecia aruensis* Edwards. *a*, Ninth sternum; *b*, genitalia, dorsal view, ninth tergum removed; *c*, ninth tergum.

They lie rather deep in the genital chamber and are visible only from end view or when the genitalia are tilted back (as in Fig. 2*b*). The dististyli are heavily sclerotized on their inner margins and appear to serve as supporting structures for the aedeagus; each has a small point at upper edge of the apex.

Length: Body, 5.0–7.0 mm.; wings, 6.0–8.0 mm.

FEMALE: Antennae 11-segmented, counting the small tip. The front is raised in the middle into a prominent ridge which extends from the ocelli to the antennae; this ridge is developed into a strong tubercle just before the antennae. The front and face are brownish-black in ground color and densely grayish pubescent; the tubercle at the lower part of the front is yellowish in color. The wings are darker brown fumose than in the male.

Length: Body, 7.0–9.5 mm.; wings, 10.0–12.0 mm.

The species has been found to be quite variable in size. Edwards said that it is smaller than *fulvicollis* and the wing of his type was recorded as 5.0 mm.

TYPE LOCALITY: Aru Islands.

Type in the British Museum (Natural History).

I have studied the type and numerous specimens from many localities in New Guinea (Netherlands, Papua, and Northeast), Aru, and Buru islands.

Plecia bakeri Malloch

Fig. 3*a, b*

Plecia bakeri Malloch, 1928, Linn. Soc. N. S. Wales, Proc. 53(5): 605.

Fitting in the *fulvicollis* complex because of the all rufous thorax and readily differentiated from all known *Plecia* by the genital characters of the male. The ninth sternum is produced on posterior median margin into a pair of slender lobes separated by a narrow V-shaped cleft. The claspers are rather slender, pointed, and curved inward, they extend about two-thirds their length beyond the apex of the sternum
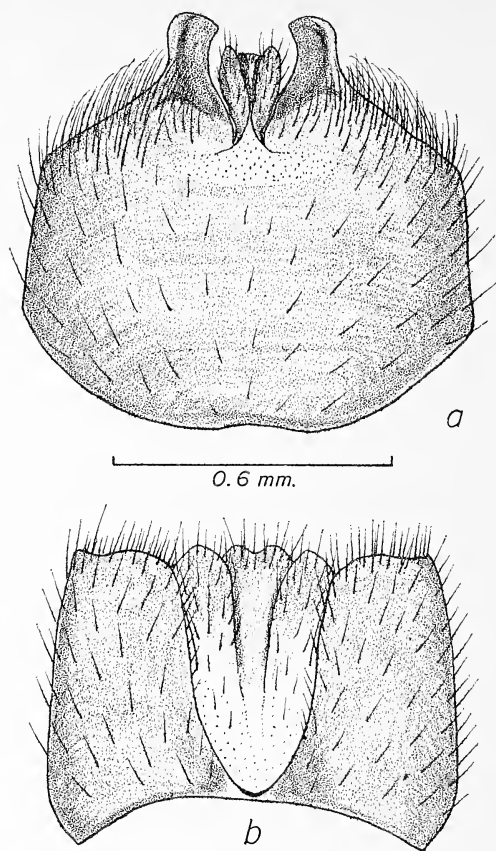
FIG. 3. *Plecia bakeri* Malloch. *a*, Ninth sterum; *b*, ninth tergum.

(Fig. 3*a*). The ninth tergum is divided into two plates by a deep V-shaped cleft on the hind margin (Fig. 3*b*).

Length: Body and wings, 6.0–7.5 mm.

Described from Baguio, Benquet, Philippine Islands. I have seen specimens from several localities on Luzon, Los Banos, Bataan, Pampanga, and Mindanao, Philippine Islands.

Type in the U. S. National Museum.

Plecia borneensis Edwards

Plecia borneensis Edwards, 1931, Jour. Fed. Malay States Mus. 16: 489, fig. 1.

A small species whose genitalia closely resemble those of *P. aruensis* Edwards. It is differentiated by having the pleura dark; the male with but six segments in the antennal

flagellum, the front tarsi of the male stout and somewhat flattened, and the ninth tergum developed into a pair of small lobes at apex, these are separated by a U-shaped cleft (see Edwards, *loc. cit.*, fig. 1).

Length: Body and wings, 4–6 mm.

Known only from the type taken at Bettotan, Borneo.

Type in the British Museum (Natural History).

Plecia burmensis n. sp.

Fig. 4a, b

Fitting in the *impostor* complex by having the pleura all black and the mesonotum rufous with a black spot in middle of the front margin. In my key to this group (Hardy, 1953, Rec. Indian Mus. 50(1): 90) it runs in couplet 3 to *malabarana* Hardy and is very closely related to this species. It differs by having the lobes of the tergum curved inward, broad, truncate at apices, not tapered (best seen from lateral view), and the median cleft is more narrowly U-shaped; rather than the lobes being straight, evenly tapered to a subacute apex and the cleft broadly U-shaped. Also the posterior lateral margins of the ninth sternum are evenly tapered into a moderately large pointed lobe lying just outside each clasper and extending three-fourths the distance to apex of clasper and the claspers are rather gently tapered to a subacute apex (Fig. 4a). In *malabarana* the posterior lateral margins of the sternum are just slightly elevated and a small inconspicuous lobe is present just outside each clasper, also the claspers are extended into a sharp pointed apical projection.

MALE. *Head:* Antennae black, tinged with rufous on basal segments, 9-segmented. Ocellar tubercle large. *Thorax:* As stated above, the blackened portion covering the anterior fourth of the mesonotum. Halteres with yellow to rufous stems and brown to black knobs. *Legs:* Brown to black, segments slender. *Wings:* Faintly brownish fumose, stigma not darker
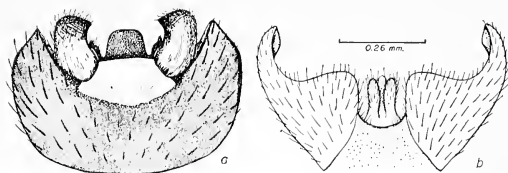
FIG. 4. *Plecia burmensis* n. sp. *a*, Ninth sternum; *b*, ninth tergum.

than the membrane. Vein R_{2+3} at about a 50° angle to R_{4+5}. *Abdomen* and *genitalia:* Entirely black with considerable gray pubescence on the dorsum. Genitalia as described above and as in Figure 4a, b.

Length: Body, 3.3 mm.; wings, 3.9 mm.

FEMALE: Like the male except for sexual differences and except that the mesonotum is entirely rufous. Head densely gray pubescent, front raised down the median portion. Bases of femora yellowish tinged.

Length: Body, 3.9 mm.; wings, 5.0 mm.

Holotype male, allotype female, and two paratype females, Upper Burma, Nam Tamai Valley, Lat. N. 27° 42', Long. E. 97° 54', 3,000 ft. elev., Aug. 1938 (R. Kaulback).

Type and allotype returned to British Museum (Natural History). One paratype each in the U. S. National Museum and the University of Hawaii collection.

Plecia buruensis Edwards

Plecia buruensis Edwards, 1926, Treubia 7: 135.

This species fits near *P. tjibodensis* Edwards but the male genitalia are distinctive. It is best distinguished by the shape and development of the ninth sternum and clasping structures as figured by Edwards (*loc. cit.*, fig. 1). The sternum is but little wider than long, the hind margin is but slightly concave and has a pair of small median lobes. The claspers are short and broad and abruptly attenuated at apices. The ninth tergum is deeply cleft on hind margin.

Length: Body, 7.0 mm.; wings, 8.0 mm.

Known only from Buru Island.

Type in the Zoologisch Museum, Amsterdam.

Plecia cana Hardy

Plecia cana Hardy, 1950, Hawaii. Ent. Soc.
Proc. 14: 76, fig. 2a, b.

A small dark-colored species related to *P. tristis* van der Wulp and differentiated by having the thorax entirely light gray with no black longitudinal stripes. The antennae are also distinctly 9-segmented; Edwards (1932, Treubia 14: 140) reported that the flagellum of *tristis* contains but four distinct segments. The male genitalia are distinctive from all known species of *Plecia*; the broad flat-topped development of the median margin of the ninth sternum and the well-developed lobes on the posterior lateral margins will separate it; see figures referred to above.

Length: Body, 4.2–4.5 mm.; wings, 5.4–5.8 mm.

Known only from Benguet, Philippine Islands.

Type in the U. S. National Museum.

Plecia decora Hardy

Fig. 5

Plecia decora Hardy, 1950, Hawaii. Ent. Soc.
Proc. 14: 78, fig. 3a–c.

Related to *P. forcipata* Osten Sacken and *forficula* Edwards because of the forcipate development of the male genitalia. It is characterized from other *Plecia* by the coloration and by the details of the male genitalia.

Predominantly dull reddish species, with three brownish-red vittae on the mesonotum. Coxae, trochanters, and bases of femora yellowish. Wings faintly brown fumose. Vein R_{2+3} forms about a 40° angle to R_{4+5}. Male genitalia as in Figure 5 and as described and figured in original. Claspers bilobed as seen from lateral view, with a sharp pointed secondary subbasal lobe arising from dorsal portion.

Length: Body, 5.0–7.0 mm.; wings, 8.0–10.0 mm.

TYPE LOCALITY: Mt. Tafa, Papua.

Type in the British Museum (Natural History).
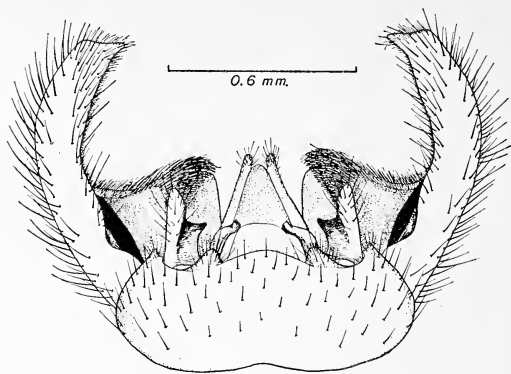
FIG. 5. *Plecia decora* Hardy. Genitalia, ventral view.

I have studied a large series of specimens from the Rijksmuseum v. Natuurlijke Historie, Leiden, and the Bernice P. Bishop Museum New Guinea Exped.: Moss Forest Camps 13, 14, 16, 19, and 31, 2800 m.; from Scree Valley Camp, 3800 m., Nov. 1938 (L. J. Toxopeus); from Araboebivak, Wisselmeren, Paniai, New Guinea, 1750 m., Sept.–Nov. 1939 (H. Boschma); and Daulo Pass, 2400 m., (Asaro–Chimbu div.), June 15, 1955 (J. L. Gressitt).

Plecia dimidiata Macquart

Fig. 6a, b

Plecia dimidiata Macquart, 1846, Dipt. Exot., Sup., p. 20, fig. 8.

Related to *P. borneensis* Edwards but distinguished by the genital characters. The ninth sternum has a well-developed flat-topped lobe in middle of hind margin and a pair of smaller submedian lobes. The claspers are expanded and dentate apically and extend well beyond apices of the tergum (Fig. 6a). The ninth tergum has a deep V-shaped cleft on hind margin (Fig. 6b).

The mesonotum is chiefly semipolished rufous with the front margin broadly blackened. The black coloration extends to a level slightly behind the humeri. The pleura are all black. The legs are all black with black pile. The femora are moderately swollen. The
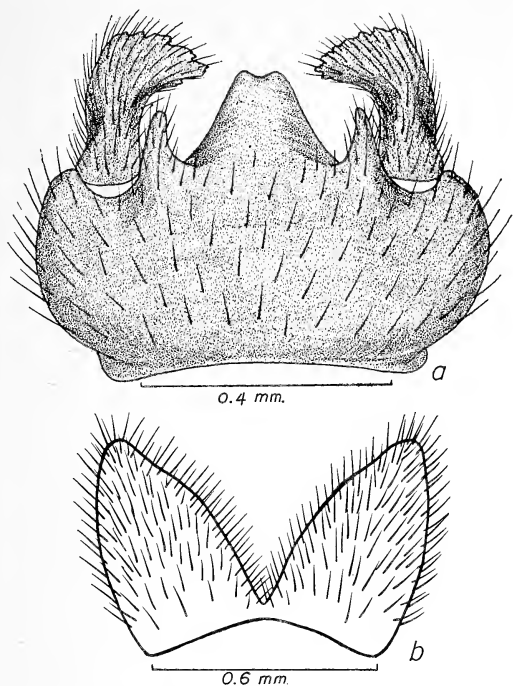
FIG. 6. *Plecia dimidiata* Macquart. *a*, Ninth sternum; *b*, ninth tergum.

wings are light-brown fumose.

Length: Body, 5.0–6.0 mm.; wings, 4.5–6.5 mm.

Described from Tasmania, known also from Australia. The type probably has been lost.

I have studied a series of specimens from both countries in the British Museum (Natural History), previously determined by Edwards.

Plecia disjuncta n. sp.
Fig. 7*a–c*

An all-black species (males) closely related to *P. monticola* n. sp. and fitting the description of that species in all details of the male except for the genitalia. It is readily distinguished by the development of the lobes of the ninth sternum as shown in Figure 7*a* and described below.

MALE. *Genitalia:* Ninth tergum divided into two plates connected at bases by a narrow sclerotized line (Fig. 7*c*). The ninth sternum is greatly expanded laterally and extends around the sides of the genitalia (Fig. 7*b*); the posterior lateral lobes are comparatively broad, rounded at apices, and serrated just below apices on inner margins (Fig. 7*a*). The claspers are slender, attenuated, shaped approximately as in *monticola*.

Length: Body, 3.0 mm.; wings, 3.8 mm.
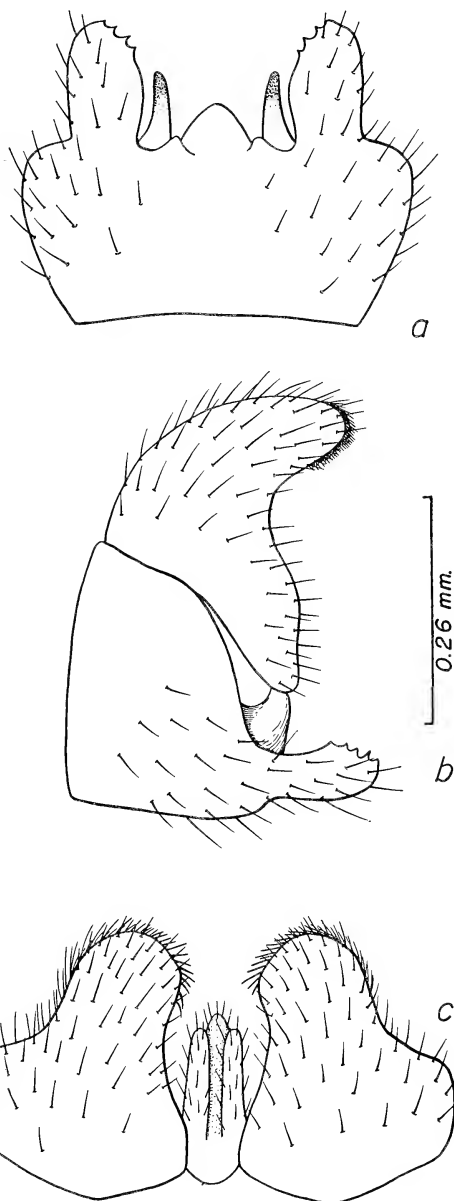
FIG. 7. *Plecia disjuncta* n. sp. *a*, Ninth sternum; *b*, genitalia, lateral view; *c*, ninth tergum.

FEMALE: Antennae 7-segmented. Thorax entirely rufous except for brown markings on the pleura; sometimes the mesonotum is extensively discolored with brown. Legs, especially the femora, tinged with yellow. Abdomen with a rufous tinge on the venter.

Length: Body, 3.3 mm.; wings, 4.8 mm.

Holotype male and allotype female in copula from Wisselmeren, Okaitadi, Netherlands New Guinea, 1800 m., Aug. 8, 1955 (J. L. Gressitt). Twelve paratypes: 1 ♂, 3 ♀♀, same data as type; 1 ♂, 1 ♀, Wisselmeren, Waghete, Tigi L., Netherlands New Guinea, 1700 m., Aug. 17, 1955; 1 ♀, Wisselmeren, Enarotadi, Netherlands New Guinea, 1900 m., Aug. 19, 1955 (J. L. Gressitt); 1 ♀, Wisselmeren, Obano, 1770 m., Aug. 9, 1955 (J. L. Gressitt); and 2 ♂♂, 2 ♀♀ from Wisselmeren, Itouda, Kamo V., 1500 m., Aug. 13, 1955 (J. L. Gressitt).

Type, allotype, and 6 paratypes in the Bernice P. Bishop Museum. The remainder in the U. S. National Museum, the British Museum (Natural History), and the University of Hawaii collection.

Plecia dispersa n. name
Fig. 8a, b

Penthetria thoracica Guérin-Méneville, 1838, in Duperrey, Voy. autour du Monde sur la Corvette de la Coquille, 2: 507. Paris. Preoccupied by *Laphria thoracica* Fabricius, 1805, System. Antl., 163, a synonym of *Plecia collaris* (Fabricius).

Plecia confusa Malloch, 1928, Linn. Soc. N. S. Wales, Proc. 53: 605, *nec P. confusa* Loew. New synonym. By comparison of the type in the British Museum with specimens of *P. thoracica* Guérin, which had been determined by F. W. Edwards.

Plecia mallochi Hardy, 1948, Kans. Ent. Soc. Jour. 21: 36. Change of name for *P. confusa* Malloch, preoccupied by *P. confusa* Loew, 1858, Berlin. Ent. Ztschr. 2: 109. New synonym.

A moderately large species with the thorax all rufous and the ocellar triangle reduced in
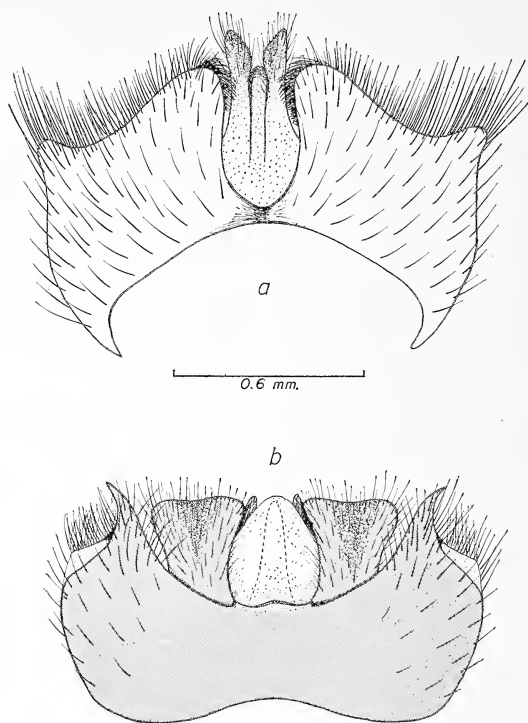
FIG. 8. *Plecia dispersa* n. name. *a*, Ninth tergum; *b*, ninth sternum.

size. It is related to *P. javensis* Edwards but the male genitalia are differently developed; the blunt claspers and the differences in the shape and development of the ninth sternum and tergum (Fig. 8a, b) will readily differentiate *dispersa*.

The ocellar tirangle is rather inconspicuous, about equal in length to about five eye facets and about one-third normal size. Antennae chiefly brown to black, rufous on basal segments; 10-segmented in male and 11-segmented in female. Ninth tergum of male about two times wider than long, with a deep rather narrowly **U**-shaped cleft in the middle of the hind margin; the apical lobes of the tergum are heavily sclerotized and densely haired (Fig. 8a). Ninth sternum of male over two times wider than long, narrow through the median portion, with the posterior lateral margins produced into pointed lobes. Claspers about two times longer than wide, blunt and

rounded at apices, and with a narrow sclero-tized bridge joining them at bases (Fig. 8*b*). Aedeagus with a pair of slender, rodlike accessory structures.

Length: Body, 7.5–8.5 mm.; wings, 8.5–9.3 mm.

TYPE LOCALITY: (Of *P. thoracica* Guérin) Coromandel, S. E. India.

Type probably in the Muséum National d'Histoire Naturelle, Paris.

This is one of the common species of India and Ceylon. I have seen specimens from several localities on Ceylon; from Mysore, Nilgiri Hills Coimbatore, S. Malabar, Katihar, N. Bengal, and from Tezpur, Assam, India. Also a female from Naukauri, Nicobar Islands, appears to be this species.

Edwards also recorded this from many localities in India and Ceylon and said that Brunetti's records of *Plecia fulvicollis* Fabricius should refer to this.

Plecia dorsalis Walker

Plecia dorsalis Walker, 1857, Linn. Soc. London, Proc. 1: 5. Preoccupied by *Plecia dorsalis* Macquart, 1838, Dipt. Exot. 1: 86.

It is impossible to place Walker's *dorsalis* and this species must be treated as a *species dubium*. In the original description, Walker indicated that both sexes were present in his type series from Singapore and Mount Ophir. No type was designated and the description, based only upon color, would fit both sexes of all of the species of the *fulvicollis* complex (those with the thorax entirely rufous). If Walker had a male (or males) in the original series, it has apparently been lost. I could not find it in the British Museum (Natural History) collection. At least part of Walker's series is in the National Museum of Victoria, Melbourne, Australia. A. Neboiss has reported that they have one female specimen from Singapore and one female from "Mt. Ophir, one wing missing, abdomen glued on and belonging to a different species of Diptera."

Without a male from one of the two localities mentioned by Walker, it is impossible to place this species. Walker later recorded *dorsalis* from the Aru Islands, Borneo, Mysol, and Amboyna but it is probable that he had a mixture of species before him. One male from Sarawak, Borneo, in the National Museum of Victoria, has been studied by A. Neboiss and from the drawings which he made at my request it is obviously a specimen of *P. subvarians* Walker.

P. dorsalis Walker has commonly been treated in the literature as a synonym of *P. fulvicollis* (Fabricius) but it is not possible to confirm this synonymy. Brunetti (1912, Fauna of British India, Diptera Nematocera, p. 163) was obviously in error when he recorded *dorsalis* from India as a synonym of *P. fulvicollis* (Fabricius).

Plecia dubia Edwards
Fig. 9*a–c*

Plecia dubia Edwards, 1928, Jour. Fed. Malay States Mus. 14: 44, figs. 39, 39a.

The genitalia show relationship with *P. amplipennis* Skuse but the specimens are much smaller, the pleura are predominantly brown to black, and the genital structures are differently developed (Figs. 9*a*, 1*a*).

A moderately small species, somewhat variable in size. Antennae 9-segmented in male, 11 in female, entirely black except for a rufous tinge at apices of basal segments. Ocellar tubercle large and conspicuous. Thorax entirely rufous on the dorsum and on the lower portion of the pleura. Upper half of pleura dark brown to black. Stems of halteres yellow, knobs brown. Legs brown to black, rather stout, segments straight. Wings light brown fumose, darker along the costa, stigma not darker than the membrane. Vein R_{2+3} arises just slightly before the middle of the distance from r-m to the wing margin, is about equal in length to r-m and nearly vertical in position. Ninth tergum with a U-shaped cleft in middle of hind margin, hind margin and postero-
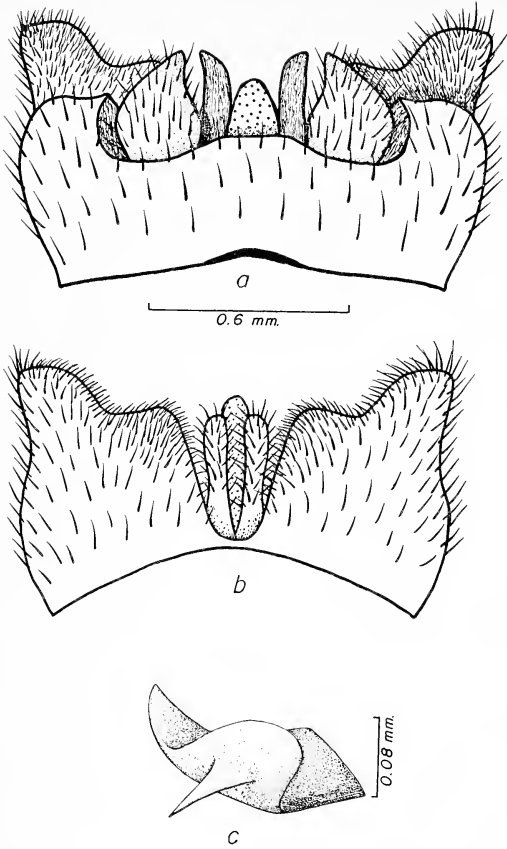
FIG. 9. *Plecia dubia* Edwards. *a*, Ninth sternum; *b*, ninth tergum; *c*, accessory structure of aedeagus, end view.

dorsal surface very densely black pilose (Fig. 9*b*). The claspers are short and broad, slightly pointed apically. The ninth sternum is approximately three times wider than long, not distinctly lobate on hind margin (Fig. 9*a*). The aedeagus has a pair of heavily sclerotized rather rodlike accessory structures, each of these possess a small sharp pointed subapical ventral lobe and a long dorsal lobe is developed, these are visible only in end view (Fig. 9*c*).

Front of female with a strong black tubercle in middle at lower margin but with no ridge down the middle.

Length: Body, 3.5–6.0 mm.; wings, 4.0–7.5 mm.

TYPE LOCALITY: Singapore.

Type in British Museum (Natural History).

I have studied the type and a series of specimens from Borneo, 1903 (R. Shelford), and Samarang, Java, Aug. 1909 (E. Jacobson), which appear to belong here.

Plecia erebea Skuse
Fig. 10*a–c*

Plecia erebea Skuse, 1889, Linn. Soc. N. S. Wales, Proc. (2)3: 1375.

This is the only all dark-colored *Plecia* known from Australia. It is distinguished from the other members of this complex from other areas by the characteristics of the male genitalia (Fig. 10*a–c*).

MALE: Entirely brownish black to black, all pile black, dense on abdomen and legs. Eyes bare, ocellar tubercle prominent. Antennae 10-segmented, counting the small nipplelike apices. Thorax subshining with a faint brownish tinge in the ground color. Dorsum sparsely
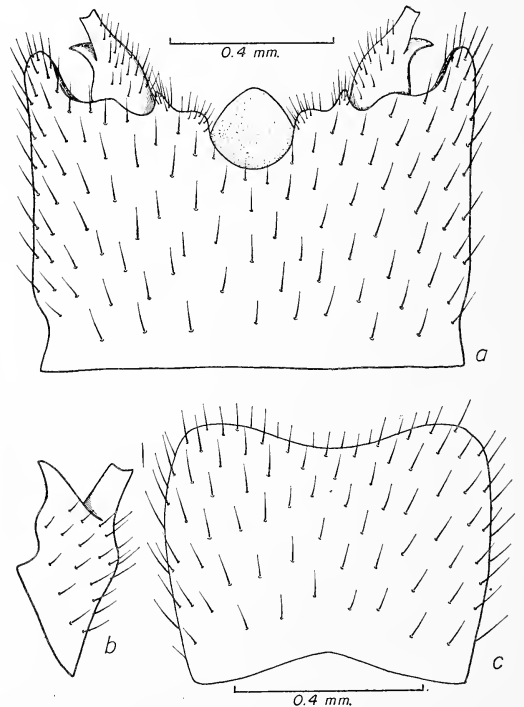
FIG. 10. *Plecia erebea* Skuse. *a*, Ninth sternum; *b*, clasper, lateral view; *c*, ninth tergum.

pilose, dorsocentral hairs very short. All leg segments slender, tibiae not at all enlarged at apices. Tibial spurs all black. Wings dark brown fumose, darkest along the anterior margin. The stigma are not well differentiated from the wing membrane. Vein R_{2+3} gently curved, forming about a 50° angle with R_{4+5}. The section of M_{1+2} from the fork to the r-m cross vein is nearly one-half longer than the cross vein. The cubital cell is not at all narrowed at its apex. Abdomen faintly shining, lightly tinged with brown in ground color. The ninth tergum is almost as long as wide and the hind margin is gently concave (Fig. 10c). The sternum has a moderately large, obtuse lobe at each side on hind margin and a smaller inconspicuous lobe just inside each clasper. The median portion of the hind margin has a broadly U-shaped concavity (Fig. 10a). The claspers are bilobed; the ventral lobe is square tipped and the dorsal lobe is acutely pointed (Fig. 10a, b).

Length: Body, 5.5 mm.; wings, 6.0–6.3 mm.

FEMALE: Head shining black in ground color, densely grayish pubescent and wider than long from a dorsal view. The antennae appear to be 11-segmented but the last two are very closely joined. The front has a small, shining black tubercle in middle just above the antennae. Otherwise like the male, except for genital characters.

Length: Body, 5.0–5.5 mm.; wings, 7.0–7.5 mm.

TYPE LOCALITY: Lawson, Blue Mountains, Australia.

Type in the Australia Museum.

The above described specimens were from Malanda, North Queensland (G. F. Hill).

Plecia forcipata Osten Sacken

Fig. 11a, b

Plecia forcipata Osten Sacken, 1881, Ann. del Mus. Civ. di Storia Nat. di Genova 16: 397.

This species may be somewhat variable, some of the specimens which I have seen from the British Museum collection have the dorsum of thorax orange, including scutellum and metanotum, and the pleura marked with black. The type male in the Museo Civico di Storia Naturale, Genova, has the thorax entirely rufous. The original description mentions a characteristic uninterrupted reddish stripe which extends across the pleura from one halter to the other, this is the case in the specimens in the British Museum collection; the metapleura, lower part of pteropleura, and all of sternopleura are rufous and the propleura, mesopleura, and hypopleura are black. The strongly forcipate ninth tergum allies this to *forficula* Edwards but the claspers and sternum are differently developed as pointed out in the above key and as shown in Figures 11a and 12a. The tergum of the type fits my
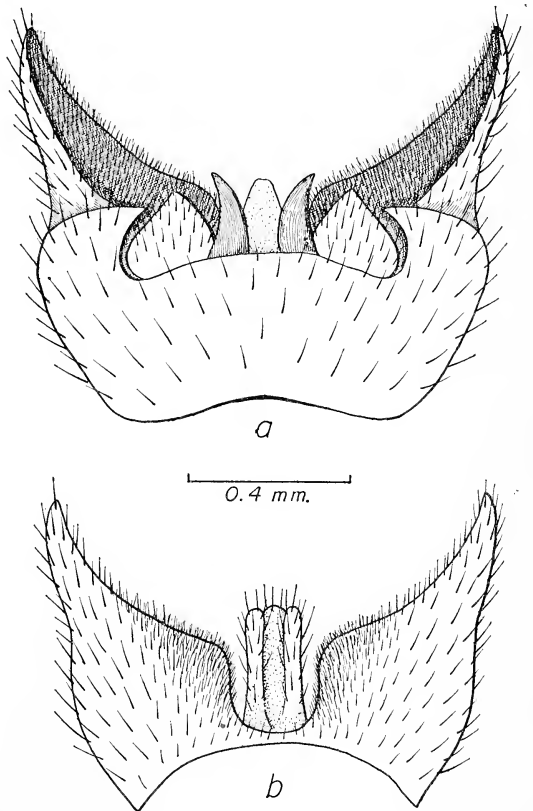
FIG. 11. *Plecia forcipata* Osten Sacken. *a*, Ninth sternum; *b*, ninth tergum.

concept of the species but it was studied *in situ* and the details of the sternum and claspers could not be seen. It is possible that two species may be involved in this concept.

MALE: Ocellar tubercle well developed. Antennae 9-segmented, apical segment equal in length to the penultimate. Legs rather short and stout, femora moderately swollen on apical portions, tibiae slender. Wings brownish fumose, darker along anterior margin. Vein R_{2+3} straight or nearly so, forming a 75° angle with R_{4+5}. Petiole of cell M_1 not over one-half longer than r-m cross vein. Cubital cell noticeably narrowed at apex, apex about one-half as long as r-m cross vein. Abdomen dark brown to black, not so densely pilose as in most species. The lobes of the ninth tergum are narrow and pointed, nearly two times longer than the sternum (Fig. 11*b*). The claspers are short and broad, rather blunt at apices. A pair of sharp pointed accessory organs are present along sides of the aedeagus. The ninth sternum is about two times wider than long (Fig. 11*a*).

Length: Body, 7.0–8.0 mm.; wings, 6.5–7.0 mm.

TYPE LOCALITY: Sumatra.

Type in the Museo Civico di Storia Naturale, Genova.

I have studied the type and specimens from Sumatra, New Guinea, and Christmas Island, Indian Ocean; de Meijere recorded it from Java.

Plecia forficula Edwards
Fig. 12*a, b*

Plecia forficula Edwards, 1928, Jour. Fed. Malay States Mus. 14: 44, fig. 40.

Similar to *P. minor* Edwards but larger and the genitalia are quite differently developed; the strongly forcipate ninth tergum will differentiate it. *P. forficula* Edwards is separated from *forcipata* Osten Sacken by the development of the claspers and sternal structures of the male genitalia as shown in Figures 12*a* and 11*a* and as pointed out in the above key.

MALE: Head black. Antenna 9-segmented, counting the nipplelike tip. Ocelli situated on a strong tubercle. Rostrum short, not over three-fourths as long as antenna. Thorax chiefly opaque, mesonotum, scutellum, metanotum, and lower portion of pleura rufous; upper half of pleura with brown to black discolorations. Legs black, segments slender; front tibiae not at all thickened, much narrower than femora. Wings light brown fumose, darker along costal margin. Vein R_{2+3} rather straight, forming about a 75° angle with R_{4+5}. Petiole of cell M_2 two times longer than r-m
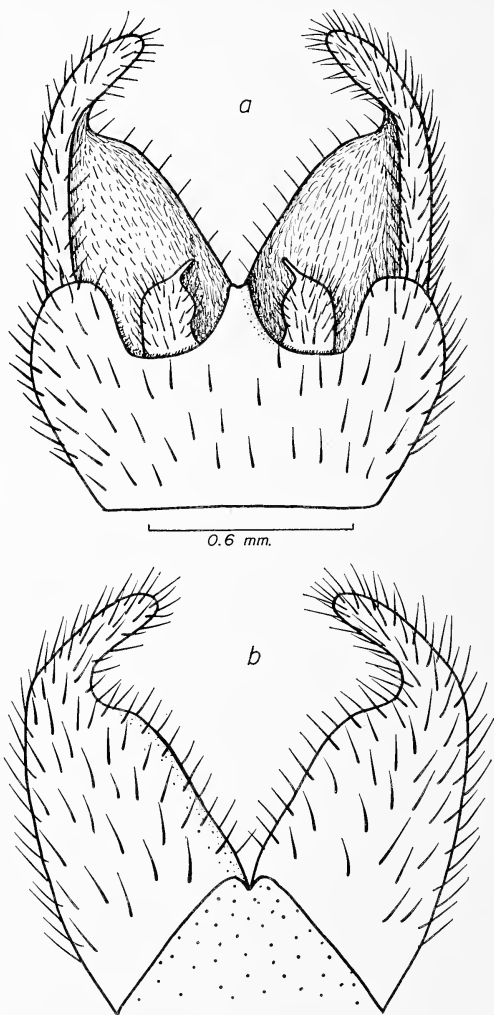
FIG. 12. *Plecia forficula* Edwards. *a*, Genitalia, ventral view; *b*, ninth tergum.

cross vein. Cell C$_u$ not narrowed. Abdomen and genitalia black. Ninth tergum strongly forcipate, the lobes slender and curved inward (Fig. 12*b*). Ninth sternum almost two times wider than long, a broad rounded lobe is developed on the posterior lateral margin and a rather narrow truncate lobe is present in the middle on the hind margin. Each clasper is developed into an elongate slender lobe at apex (Fig. 12*a*).

The female antennae are apparently 11-segmented and according to Edwards the pleura are less extensively blackened.

Length: Body, 6.0–7.0 mm.; wings, 9.0 mm.

TYPE LOCALITY: Pahang, Lubok Tamang.

Type in the British Museum (Natural History).

I have studied the type and specimens in the British Museum from Pahang Federated Malay States, Cameron's Highlands, at light, 4,800 ft., Mar. 13, 1925 (H. M. Pendlebury).

Plecia fulvicollis (Fabricius)

Fig. 13*a–c*

Hirtea fulvicollis Fabricius, 1805, System. Antl., 53.

Plecia philippinensis Malloch, 1928, Linn. Soc. N. S. Wales, Proc. 53(5): 605. New synonym.

The synonymy of *philippinensis* Malloch is based upon the comparison of specimens of *fulvicollis* (Fabricius) from Sumatra, which had been identified by Dr. F. W. Edwards, with a large series of specimens from the Philippines which fit Malloch's description and figure.

A number of distinct species have been confused in the literature under the name *fulvicollis;* some authors used this name for all Pacific and oriental *Plecia* which have the thorax entirely rufous.

This species is close to *P. bakeri* Malloch and is differentiated by the differently developed genitalia of the male. In *fulvicollis*, the ninth tergum has a more U-shaped cleft on the hind margin (Fig. 13*a*), the lobes are rounded

0.26 mm.

0.3 mm.
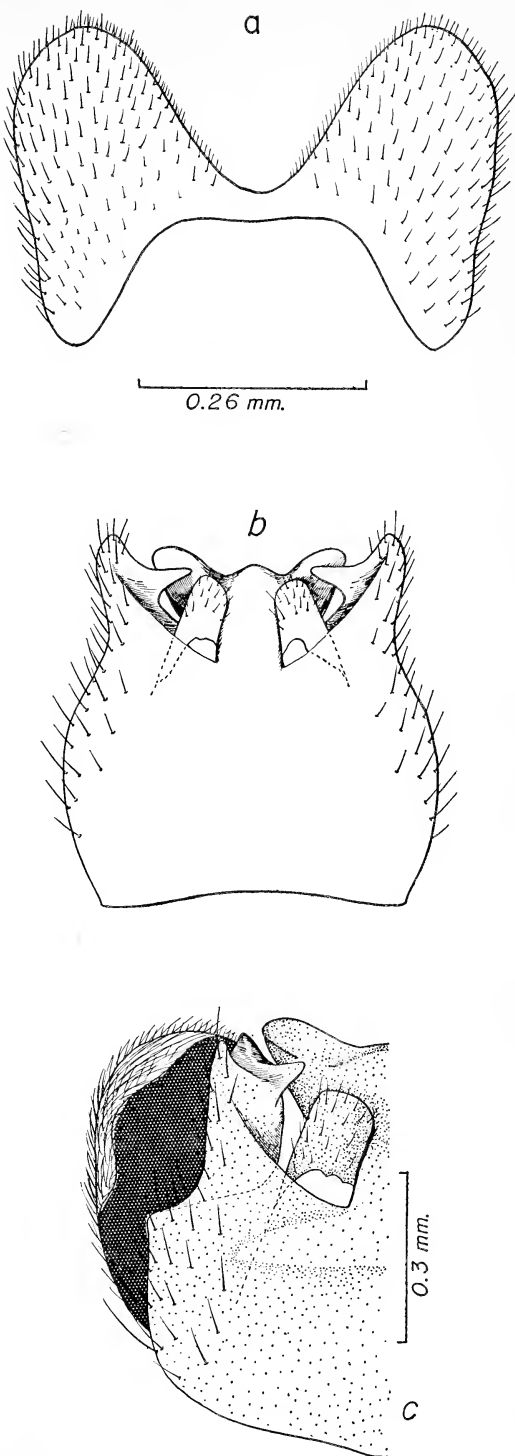
FIG. 13. *Plecia fulvicollis* (Fabricius). *a*, Ninth tergum; *b*, genitalia, ventral view; *c*, ninth sternum, tilted back.

not truncate. The ninth sternum is about as wide as long, each posterior lateral margin is produced into three lobes at apex (seen in end view or slightly tilted ventral view). The posterior median margin is strongly produced into a broad, heavily sclerotized, bilobed (indistinctly trilobed and with each of the lateral lobes slightly divided subapically) process. The claspers are small, inconspicuous, rounded at apices; fused with the median process of the sternum and extending about half its length (Fig. 13b, c). The development of the ninth sternum and claspers of bakeri is very different, as shown in Figure 3a.

Length: Body, 5.7–6.0 mm.; wings, 6.0–6.4 mm.

TYPE LOCALITY: Sumatra.

The type probably has been lost.

The species is common in Sumatra (and probably all of Indonesia) and the Philippine Islands; I have seen it from a number of localities in both areas. Records from India, Australia, China, Japan, Formosa, etc., are probably errors. Ouchi (1940, Jour. Shanghai Sci. Inst., Sec. III, 4: 294) misspelled this "fluviollis." Brunetti (1912, Fauna of British India, Diptera Nematocera, p. 163) was obviously in error in recording this from India and in considering P. thoracica Guérin as a synonym.

Plecia fumida Edwards

Plecia fumida Edwards, 1933, Jour. Fed. Malay States Mus. 17: 244.

An entirely dull-black species fitting close to P. furva Hardy but with square-tipped claspers. The ninth tergum is deeply cleft on the hind margin, nearly divided into two large, triangular shaped, lobes. The posterior lateral margins of the ninth sternum are produced, rather pointed, extending beyond apices of lobes of tergum.

Length: Body, 5.0–6.5 mm.; wings, 6.5–9.0 mm.

The species has not been figured.

TYPE LOCALITY: Tenompok Pass, Borneo.

Type in the British Museum (Natural History).

Known only from Borneo.

Plecia fumidula Edwards

Plecia fumidula Edwards, 1933, Jour. Fed. Malay States Mus. 17: 244.

An entirely black species resembling P. fumida Edwards but much smaller and with quite different genitalia. It is related to P. furva Hardy but differentiated by having the lobes of the ninth sternum extending well beyond the apices of the tergum, the tergum extends only about two-thirds the length of the sternum. The ninth sternum is not so deeply cleft as in furva, the submedian lobes on the hind margin are much more slender and the claspers are comparatively small and each has a sharp pointed subapical lobe on the inner margin. (Refer to description of the genitalia and fig. 2a, b, Hardy, 1952, Beitr. z. Ent. 2: 428.)

Length: Body and wings, 3.5–5.5 mm.

TYPE LOCALITY: Mt. Kinabalu, Borneo.

Type in the British Museum (Natural History).

Known only from Borneo; I have studied the type and type series in the British Museum.

Plecia fumidula diversa n. sub. sp.
Fig. 14a, b

Specimens on hand from New Britain seem to fit P. fumidula Edwards in all respects except that the thorax is entirely orange to rufous, except for the brown to black propleura; rather than the body all black as in the typical form. I see no significant differences in the male genitalia and feel that in spite of a few minor differences which I see in the specimen at hand and the drawings I made of a co-type of fumidula (Hardy, 1952, Beitr. z. Ent. 2: 428, fig. 2a, b) this should be treated as a subspecies. Perhaps more significant differences will be found when a series is studied.

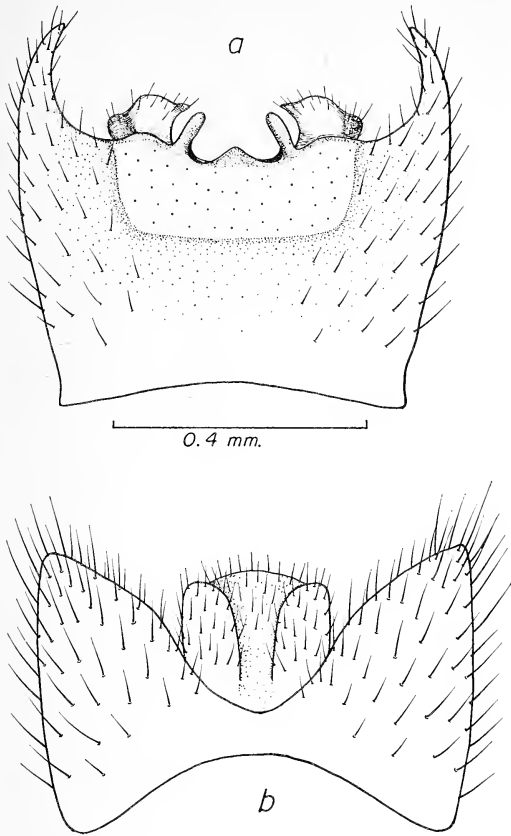The antennae of the male are all black and made up of 9 distinct segments. In the female

FIG. 14. *Plecia fumidula diversa* n. subsp. *a*, Ninth sternum; *b*, ninth tergum.

the antennae are 11-segmented, with the last two closely joined and the basal segments are brownish yellow. The propleura are orange colored in the female, brown to black in the male. The halteres and legs are black, with a yellow tinge in the ground color of the femora in the female. Tibiae or tarsal segments not swollen. Wings brown fumose, darker in the male. Vein R_{2+3} slightly curved in the male and straight in the female, entering the costa at about a 65° angle to R_{4+5}. The lobes on posterior lateral margins of the ninth sternum of the male are slender, sharply pointed, and slightly curved inwardly. A narrow submedian lobe is present on the sternum just inside each clasper and the median portion is raised into a small mound. The claspers are small, rounded

at apex, produced into a sharp, beaklike subapical point on inner side and with a rather broad lateral expansion on outer side (Fig. 14*a*). The posterior median third to two-fifths of the sternum is membranous. The ninth tergum is deeply cleft, the lobes are subacute at apices (Fig. 14*b*).

Length of male: Body, 4.8 mm.; wings, 5.5 mm.

Length of female: Body, 3.5 mm.; wings, 4.8 mm.

Holotype male and allotype female, Kerawat, Gazelle Pen., New Britain, 60 m., Aug. 31, 1955 (J. L. Gressitt).

Both in the Bernice P. Bishop Museum collection.

Plecia furva Hardy

Plecia furva Hardy, 1952, Beitr. z. Ent. 2: 429.

An all dark colored species related to *P. fumidula* Edwards, it fits the original description in all details except that the claspers of *fumidula* were described as "small and rounded." *P. furva* is differentiated from *fumidula* by the more elongate ninth tergum, the lobes extending beyond the apices of the sternum. The lobes of the ninth sternum are much broader at their bases and are gently tapered to a sharp point at their apices; the cleft on the hind margin extends about two-thirds the length of the sternum, rather than less than half the length. The claspers are also much more developed in *furva*, they are strongly curved with a capitate, rounded, apical lobe and with the basal portion slightly hollowed out and expanded laterally; no lobe present on inner margin (refer to complete description *op. cit.*: 429–431, fig. 3a, b).

Length: Body and wings, 5.5 mm.

TYPE LOCALITY: Segare Anak, Lombok, Lesser Sunda Islands.

Type in the Deutsches Entomologisches Institut, Berlin.

Plecia gurneyi Hardy

Plecia gurneyi Hardy, 1950, Hawaii. Ent. Soc. Proc. 14: 79.

Fitting in the group of species which have the mesonotum bright orange and the pleura brown to black. It is related to *P. laffooni* Hardy and is distinguished only by the male genital characters. In *gurneyi* the ninth tergum is much broader, the cleft on the hind margin is broadly V-shaped so that the lobes of the ninth tergum are widely divergent at their apices, the claspers are much better developed than in *laffooni* and extend well beyond the apices of the submedian lobes extending from the hind margin of the sternum. The lobes on the posterior lateral margins of the sternum are tiny, poorly developed, not elongated as in *laffooni*. The accessory structures of the aedeagus are rather inconspicuous and barely protrude beyond the hind margins of the sternum, rather than strong and produced beyond apices of claspers as in *laffooni* (refer to Hardy, *op. cit.*: 81 and 83, figs. 4a, b, 6a, b).

Length: Body, 4.0–4.5 mm.; wings, 6.0 mm.
TYPE LOCALITY: Bougainville Island.
Type in the U. S. National Museum.

Plecia inconspicua Hardy

Fig. 15a–c

Plecia inconspicua Hardy, 1950 Hawaii. Ent. Soc. Proc. 14: 79.

A moderately small species in the complex which has the dorsum of the thorax chiefly rufous and the pleura brown to black. It is related to *P. malayaensis* Hardy because of the forcipate lobes of the ninth sternum. It is differentiated by having the lobes of the ninth tergum more acutely pointed at apices, rather than broad and truncate; by having the claspers rather triangular in shape and with a narrow lobe extending from posterior submedian margin of sternum alongside of each clasper and also by having the ninth sternum largely membranous in the central portion (Fig. 15a), not sclerotized. I misinterpreted the characteristics of the claspers and hind margin of the ninth sternum in the original description. After studying more completely cleared specimens a pair of submedian lobes have been
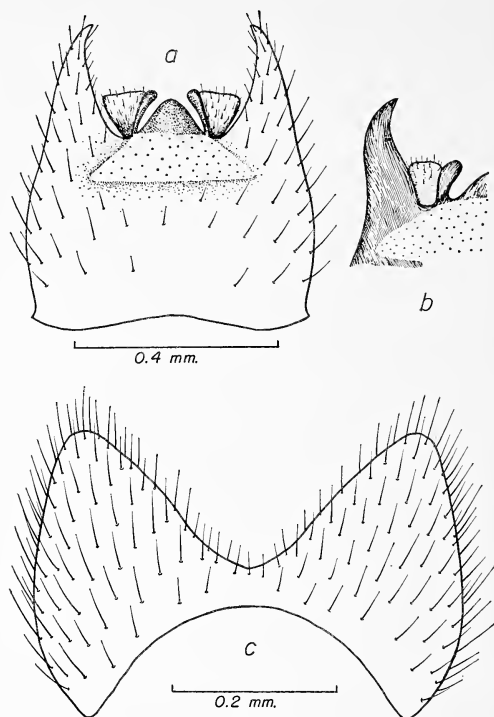
FIG. 15. *Plecia inconspicua* Hardy. *a*, Ninth sternum; *b*, ninth sternum, tilted to left showing submedian lobe; *c*, ninth tergum.

found the stone rnum, these lie very close to the inner margins of the claspers and are easily overlooked (Fig. 15b). Also the lobes of the ninth tergum are subacute, not sharply pointed in the specimens at hand (Fig. 15c). For a more complete description refer to the original.

Length of type: Body, 3.0 mm.; wings, 3.75 mm.
TYPE LOCALITY: Kokoda, Papua.
Type in the British Museum (Natural History).

Specimens on hand from Wisselmeren, Waghete, Tigi L., New Guinea (Netherlands), 1700 m., Aug. 17, 1955 (J. L. Gressitt) are slightly larger than the type: body, 4.0–4.2 mm.; wings, 5.0–5.3 mm.

Plecia javensis Edwards

Plecia javensis Edwards, 1925, Treubia 6: 158.

A large species with the thorax all rufous and the wings brown to blackish fumose. It is

related to *P. thoracica* (Guérin) and is separated by the genital characters of the male. The claspers of *P. javensis* are produced into elongate slender lobes at their apices while the claspers of *thoracica* are blunt, rounded at apices not developed into an apical lobe. The aedeagus and its accessory structures, the ninth sternum, tergum, and cerci are also differently developed in the two species. In *javensis* the ninth tergum is two times wider than long and has a V-shaped cleft almost to its base on the hind margin. The posterior lateral margins of the tergum are each bilobed, the inner lobe is broader, more blunt than is the outer. The cerci are broad, well developed, and extend well beyond the apices of the tergum. The ninth sternum is very broadly concave on the hind margin, at the median portion the sclerite is less than half as long as at lateral margin; the posterior lateral margins are sharply pointed. The claspers are very irregular in shape, are extended into slender lobes on inner apices, and are apparently fused together by a narrow sclerotized bridge connecting their inner bases. The aedeagus has an elongate rodlike accessory structure on each side, extending beyond apices of claspers. (Refer to figs. 4a, b, Hardy, 1952, Beitr. z. Ent. 2: 430.)

Length: Body, 6.5–10.0 mm.; wings, 7.8–14.0 mm.

TYPE LOCALITY: Java.

Type in the British Museum (Natural History).

I have seen the type and numerous specimens from Java.

This is the species which Malloch (1928, Linn. Soc. N. S. Wales, Proc. 53: 604) determined as "*Plecia fulvicollis* Fab." The specimens were intercepted at San Francisco, "reared from orchids" (the medium in which they were growing) brought in from Java on the S. S. "Tenyo Maru."

Plecia laffooni Hardy

Plecia laffooni Hardy, 1950, Hawaii. Ent. Soc. Proc. 14: 80–82, fig. 6a–c.

A medium-sized species having the dorsum of the thorax bright orange and the pleura brown to black. It fits in a complex with *P. gurneyi* Hardy and *P. manni* Hardy because of the unusual development of the male genitalia: the fingerlike claspers, the paired lobes on each posterior lateral margin, and the strong, heavily sclerotized accessory structures of the aedeagus. *P. laffooni* is readily differentiated from *manni* by the presence of the elongate rodlike submedian lobes on the hind margin of the ninth sternum (*loc. cit.*, fig. 6a). It differs from *gurneyi* by the subequal lobes of the posterior lateral margins of the sternum, the dorsal lobe is about equal in size to the clasper and extends as far as apex of clasper, rather than being short, inconspicuous, not longer than dorsal lobe. Also the submedian lobes of the sternum extend well beyond apices of claspers and the claspers are smaller; the accessory structures of the aedeagus are also much stronger in *laffooni*, extending beyond apices of claspers. In *gurneyi* the claspers are larger and the accessory structures smaller, scarcely extending beyond hind margin of sternum. The ninth tergum of *laffooni* is also longer than wide and has a deep V-shaped cleft on hind margin (*loc. cit.*, fig. 6b). See original description for more complete details.

Length: Body, 4.2–5.0 mm.; wings, 5.8–6.6 mm.

TYPE LOCALITY: Guadalcanal, Solomon Islands.

Type in the U. S. National Museum.

Plecia lieftincki n.sp.
Fig. 16*a–c*

Related to *P. ruficornis* Edwards (from Kei Island, Indonesia) but distinguished by the characteristics of the male genitalia. In Edward's species the lobes of the posterior lateral margin of the ninth sternum are elongated and pointed, extending two times farther than the claspers. In *lieftincki* the lobes are rounded at their apices and extend scarcely two-thirds as long as the claspers (Fig. 16*a*). Also the
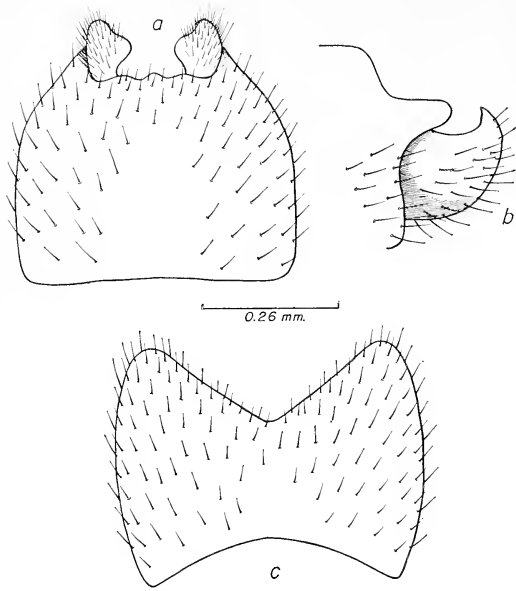
FIG. 16. *Plecia lieftincki* n. sp. *a*, Ninth sternum; *b*, clasper, lateral view; *c*, ninth tergum.

claspers are quite differently shaped in the two species.

MALE: A small species, belonging in the group which has the thorax entirely rufous. The halteres are brown, the bases are rufous. The scape and pedicel of the antenna are yellow-brown, the flagellum is brown. *Legs:* Entirely brown, all of the segments are moderately slender, not at all swollen. *Wings:* Faintly brown fumose, more distinctly so along the costa. Vein R_{2+3} straight, oblique in position forming about a 75° angle with R_{4+5}. *Abdomen:* Entirely dark brown. *Genitalia:* The ninth tergum is about two times as wide as long and has a moderate concavity extending nearly half its length on the posterior margin (Fig. 16*c*). The ninth sternum is slightly wider than long and fits the characters given above and in Figure 16*a*. The claspers are but little longer than wide, are rounded at apex, and produced into a protuberance on inner margin as viewed from below. In lateral view each clasper is seen to terminate in a sharp upward curved point (Fig. 16*b*).

Length: Body, 3.5 mm.; wings, 3.8 mm.

FEMALE: As in the male except for genital and secondary sexual characters. The flagellum of the antenna is 8-segmented (the tip is broken in the male).

Length: Body, 3.5 mm.; wings, 4.2 mm.

Holotype male and allotype female: Base Biak, 2-VIII-1952, op licht (L. D. Brongersma and W. J. Roosdorp).

Both have been returned to the Rijksmuseum van Natuurlijke Historie, Leiden, Holland.

I take pleasure in naming the species after my friend, Dr. M. A. Lieftinck, who has made such outstanding contributions in the field of entomology in Indonesia.

Plecia magnispina n. sp.
Fig. 17*a*, *b*

Related to *P. decora* Hardy but differentiated by its smaller size and by the differently developed genitalia. The lobes of the ninth tergum of the male are more strongly con-
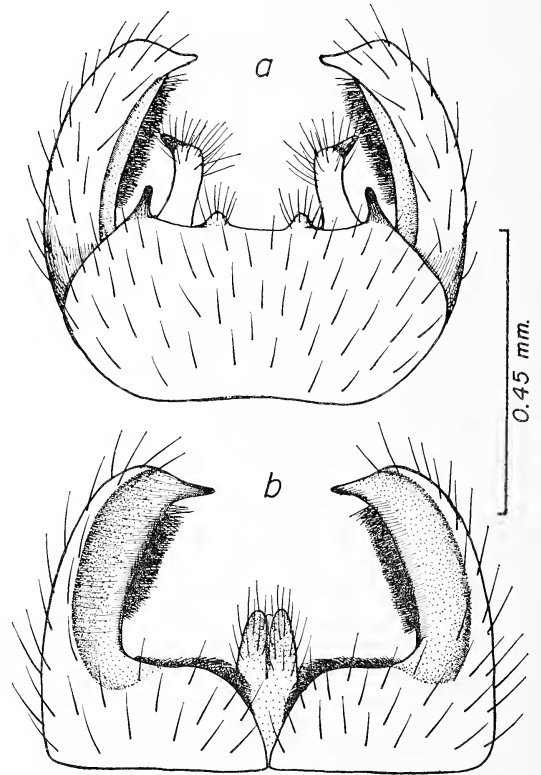
FIG. 17. *Plecia magnispina* n. sp. *a*, Genitalia, ventral view; *b*, ninth tergum.

vergent and terminate in a large apical spine, the claspers are more pointed apically, and the posterior lateral margins of the ninth sternum are developed into slender lobes (Fig. 17*a*).

MALE. *Head:* Black, including appendages. Antennae short, compact, apparently 9-segmented. Ocellar tubercle large and conspicuous. *Thorax:* Dull red with three reddish-brown to black vittae extending longitudinally down the mesonotum. Lower portion of pleura red, upper portion brownish red. Scutellum red with a black line through the middle. Halteres yellow-red, tinged with brown on their knobs. *Legs:* Coxae, trochanters, and bases of femora rufous, remainder brown tinged with rufous. *Wings:* As in *decora*, faintly fumose, vein R_{2+3} at about a 45° angle to R_{4+5}. *Abdomen* and *genitalia:* Dark brown to black. Ninth tergum with a narrow V-shaped cleft in middle of hind margin, extending nearly to base of segment; the posterior lateral margins are strongly lobate, sharp pointed at apices. The inner margins of tergum are very densely covered with short black hair (Fig. 17*b*). The ninth sternum is scarcely half as long as the tergum, is about two times wider than long, and has a sharp, slender spinelike lobe on each posterior lateral margin, also a small rounded knoblike lobe just inside each clasper. Claspers rather slender, four times longer than wide, shaped as in Figure 17*a*, as seen from a dorsal view. Each clasper with a sharp pointed lobe near base arising from dorsal surface, visible from lateral or end view. Aedeagus with a pair of rodlike accessory structures, these are slightly curved at apices.

Length: Body, 3.0 mm.; wings, 4.5 mm.

FEMALE: Fitting the above description in most respects. The front has a rather well-developed keel down the middle. The mesonotal vittae vary from brownish-red to black.

Length: Body, 3.5 mm.; wings, 5.5 mm.

Holotype male and allotype female, Wisselmeren, Obano, Dutch New Guinea, 1770 m., Aug. 9, 1955 (J. L. Gressitt). Twenty-five paratypes, 13 ♂♂ and 12 ♀♀ from following localities in New Guinea: same as type;

Wisselmeren, Paniai, Sept.–Nov. 1949 (H. Boschma); Mt. Wilhelm, 3000 m., July 4, 1955 (J. L. Gressitt); Wisselmeren, Okaitadi, 1800 m., Aug. 7, 1955 (J. L. Gressitt); Daulo Pass, 2400 m., (Asaro-Chimbu div.) June 15, 1955 (J. L. Gressitt); and Mist Camp, 1800 m., 12-I-1939 (L. J. Toxopeus).

Type, allotype, and a series of paratypes returned to the Bernice P. Bishop Museum. Remainder of paratypes distributed among the following collections: Rijksmuseum v. Natuurlijke Historie, Leiden; U. S. National Museum; British Museum (Natural History); and the University of Hawaii.

Plecia malayaensis Hardy

Fig. 18*a*, *b*

Plecia malayaensis Hardy, 1948, Kans. Ent. Soc. Jour. 21: 36. New name for *Plecia minor* Edwards, 1928, Jour. Fed. Malay States Mus. 14: 44, *nec P. minor* Jaennicki, 1867, Senckenb. Naturf. Gesell. Abhandl. 4: 318.

Related to *P. inconspicua* Hardy, from Papua, but differentiated by the truncate lobes of the
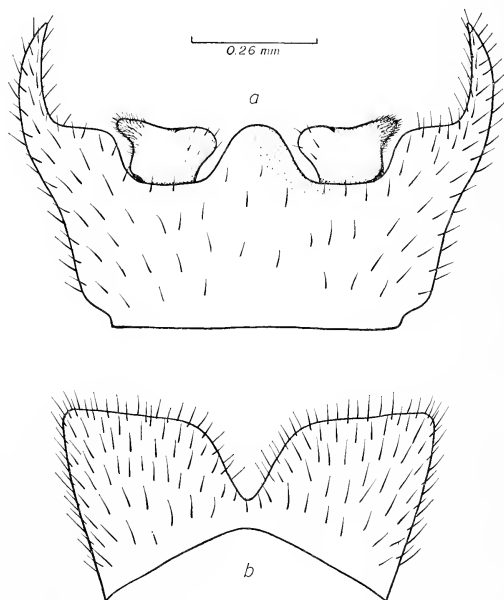
FIG. 18. *Plecia malayaensis* Hardy. *a*, Ninth sternum; *b*, ninth tergum.

ninth tergum of the male and by having the claspers pointed on the outer apices (Fig. 18a); rather than the lobes of the tergum being subacutely pointed, the claspers rather triangular, and a narrow lobe extending from the hind margin of the sternum along the inner side of each clasper (Fig. 15a).

A small species with rostrum not strongly produced and only about three-fourths as long as antennae. Antennae brown to black, 9-segmented in the male, 11-segmented in the female. Ocellar tubercle large and prominent. Mesonotum and scutellum (except for a black line down the latter) entirely opaque rufous. Pleura brown, tinged with rufous especially on sternopleura. Legs black in the male, tinged with rufous in the female. Front tibia rather strongly swollen, especially in the male, in the middle it is equal to slightly wider than the thickest part of the femur. Wings light brown fumose. Vein R_{2+3} bent near base, entering the costa at about a 65° angle to R_{4+5}. Petiole of cell M_2 not much longer than r-m cross vein. Cubital cell not at all narrowed at apex. Abdomen and genitalia dark brown to black. Ninth tergum with a V-shaped cleft in middle of hind margin, dividing the segment into two nearly quadrate lobes (Fig. 18b). The ninth sternum is rather strongly forcipate, the lobes on the posterior lateral margins are slender and sharply pointed. The posterior median margin of the sternum has a broad round-topped lobe extending approximately as far as apices of claspers. The claspers are short and broad, broadly rounded on inner apex, and with a subacute, densely setulose lobe on outer apex (Fig. 18a).

Length: Body, 4.5–5.0 mm.; wings, 5.0–6.4 mm.

TYPE LOCALITY: Mabek, Peninsular Siam.

Type in the British Museum (Natural History).

I have studied specimens in the British Museum collection from Biserat, Siam. The species probably occurs throughout Thailand and Malaya and possibly to the West through Burma and South India. Edwards recorded it from Methapalayam, S. India.

Plecia manni Hardy

Plecia manni Hardy, 1950, Hawaii. Ent. Soc. Proc. 14: 82–84, fig. 7a.

Related to *P. laffooni* Hardy and to *gurneyi* Hardy and fits the descriptions of these species except for male genital characters and except that the cubital vein is rather sharply bent downward and the cubital cell is narrower at the apex. The ninth sternum lacks the pair of slender rodlike submedian lobes which is characteristic of the other two species in this complex and the posterior median portion of the sternum is developed into a large semimembranous portion which is longer than the remainder of the segment and which extends two-thirds the length of the claspers. The aedeagus has a pair of strong, curved, and sharply pointed accessory structures which extend well beyond the apices of the claspers. For a complete description see the above reference and figure.

Length: Body, 5.0 mm.; wings, 5.7 mm.

TYPE LOCALITY: Fulakora, Solomon Islands.

Type in the Museum of Comparative Zoology.

Plecia mayoensis Hardy

Plecia mayoensis Hardy, 1950, Hawaii. Ent. Soc. Proc. 14: 84, fig. 8a, b.

Fitting in the complex which has the thorax entirely rufous and distinguished by the male genital characters. The slender stemmed, capitate lobes at the apex of the ninth sternum will separate it from all known species of *Plecia*. The apical lobes extend beyond the apices of the claspers and to the tip of the aedeagus. The claspers are short and broad, obtuse at apices. The ninth tergum has a deep U-shaped cleft on hind margin, the lobes are rounded at apices. For a more complete description and figures, refer to the above reference.

Length: Body, 9.0 mm.; wings, 8.5–9.5 mm.

TYPE LOCALITY: Mt. Mayo, Davao, Philippine Islands.

Type in the Museum of Comparative Zoology.

Plecia monticola n. sp.
Fig. 19*a–e*

An all black species (males) which along with *P. disjuncta* n. sp. is distinguished from other *Plecia* by the lateral expansion of the ninth tergum, which causes the genitalia to be wider than long in lateral view. Also the cleft of the tergum divides it into two plates connected only by a thin sclerotized line at their bases. *P. monticola* is separated from *disjuncta* by the slender pointed lobes at apex of the ninth sternum (Fig. 19*d*).

MALE. *Head:* Antenna black with a tinge of reddish brown on the pedicel and at base of first flagellar segment; composed of but six clearly defined segments, the apical portion evidently made of two closely joined segments (Fig. 19*a*). Rostrum about half as long as antennae. Ocellar tubercle prominent. *Thorax:* Opaque black, lightly gray pollinose; with a faint reddish tinge in the ground color of the humeral ridges, the areas to the sides of the scutellum, and the metanotum are sometimes yellow-brown. The halteres are brown with brownish-yellow stems. Three distinct longitudinal grooves are present on the mesonotum. *Legs:* Entirely black, the tibiae or tarsi not swollen. *Wings:* Dark brown fumose. Fork of R_s situated at the middle of the distance from base of R_s to apex of R_{4+5}, the first section of R_s is about half the length of the second. Vein R_{2+3} straight entering the costa at about an 80° angle to R_{4+5}. Cubital cell not narrowed at apex. *Abdomen* and *genitalia:* Subopaque black, rather sparsely pilose. Cleft of ninth tergum expanded in middle (Fig. 19*b*), on the inner side of each plate of the tergum is a set of strong curved bristles along the posterior inner margin; the anterior inner margin is densely covered with short, stout, black bristles, these are visible only from an inner view of the genitalia. From a lateral view (Fig.
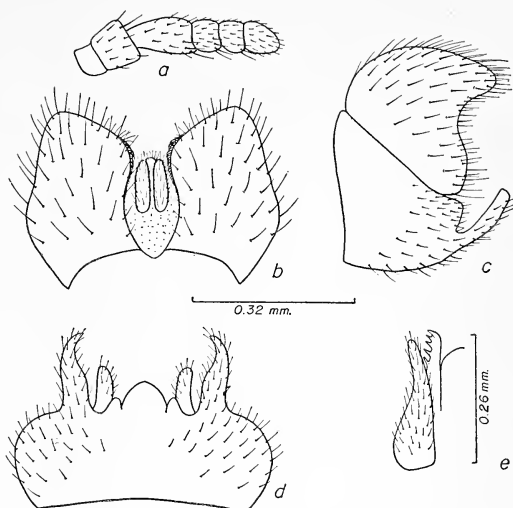
FIG. 19. *Plecia monticola* n. sp. *a*, Antenna; *b*, ninth sternum; *c*, genitalia, lateral view; *d*, ninth sternum; *e*, end view of claspers and accessory structures of aedeagus.

19*c*), the tergum is greatly expanded around the side of the genitalia. The posterior lateral lobes of the ninth sternum are about equal in length to the remainder of the segment and about two times longer than the claspers as seen in ventral view (Fig. 19*d*). A small submedian lobe lies just inside each clasper and a broad moundlike gibbosity is present in middle of hind margin of the sternum. From an end view the claspers are rather elongate and attenuated and a heavily sclerotized comblike accessory structure is visible on each side of the aedeagus (Fig. 19*e*).

Length: Body, 3.0 mm.; wings, 4.0 mm.

FEMALE: Antennae 7-segmented. Humeral ridges, sternopleura, hypopleura, metanotum, and sides of mesonotum and scutellum tinged with rufous. Wings slightly paler fumose. Femora reddish brown on the attenuated portions. Otherwise as in male except for genital characters.

Length: Body, 3.3 mm.; wings, 5.0 mm.

Holotype male, allotype female, and two male paratypes, Mt. Wilhelm, N.E. New Guinea, 3000 m., July 4, 1955 (J. L. Gressitt). Type and allotype in Bernice P. Bishop Museum. One paratype in the U. S. National Museum and one at the University of Hawaii.

Plecia morosa Edwards
Fig. 20*a, b*

Plecia tristis Edwards, 1927, Treubia 9: 362,
fig. e, *nec P. tristis* van der Wulp, 1884,
Notes Leyden Mus. 6: 251.
Plecia morosa Edwards, 1932, Treubia 14: 140.

A moderately small, opaque dark-brown to
black species, readily recognized by the dis-
tinctive genitalia of the male. The lack of de-
velopment of the posterior lateral lobes of the
ninth sternum (Fig. 20*a*) and the strong de-
velopment of the lobes of the tergum (Fig.
20*b*) will separate it from related species. Ninth
sternum about two times wider than long, the
posterior lateral margins are rounded and the
posterior median portion is raised into a semi-
membranous mound. The claspers are capi-
tate, rounded at apices, their bases seem to be
fused with the margins of the sternum (Fig.
20*a*). The ninth tergum is deeply cleft almost
to its base on the hind margin; the lateral lobes
are rather slender (Fig. 20*b*) and extend nearly
half the length of the segment beyond the
claspers.

Length: Edwards measured the body and
wings as 6.0 mm. The specimens I have seen
measured 3.35–3.75 mm. for the body and
4.5–5.2 mm. for the wings.

TYPE LOCALITY: Tjibodas, W. Java.

Type in the British Museum (Natural
History).

I have studied specimens from the type
locality.

Plecia ornaticornis Skuse
Fig. 21*a, b*

Plecia ornaticornis Skuse, 1899, Linn. Soc. N. S.
Wales, Proc. (2)3: 1374.

A moderate sized species belonging in the
complex which has the thorax entirely rufous.
It appears most closely related to *P. ruficornis*
Edwards but is larger and the male genitalia
are differently developed. The lateral lobes of
the ninth sternum are rounded rather than
sharp pointed at their apices; the claspers are
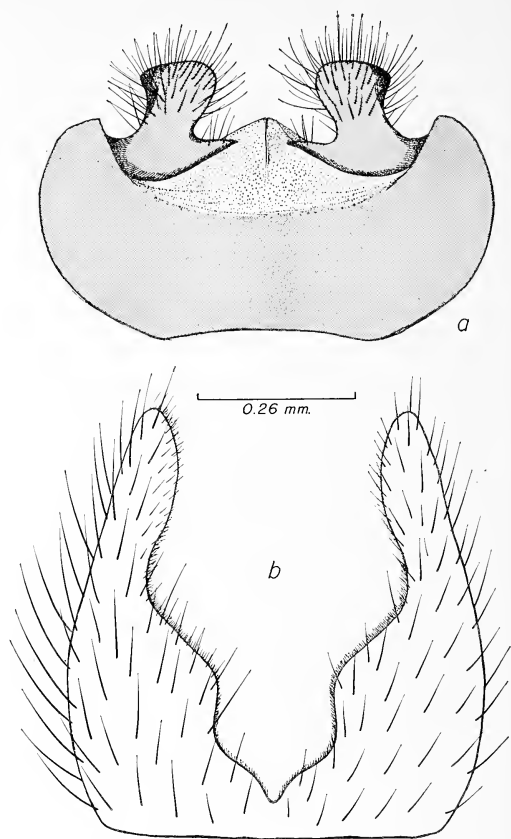
FIG. 20. *Plecia morosa* Edwards. *a*, Ninth tergum;
b, ninth sternum.

truncate, pointed on inner apices rather than
rounded and a broad rounded median lobe is
present on the hind margin of the sternum,
also the lateral lobes are closer together as in
Figure 21*a*.

MALE: Eyes very sparsely pilose. Antennae
chiefly black, 9-segmented, the second seg-
ment slightly reddish on apical half. Legs
black, segments slender. Wings light brown
fumose, darker along costal margin. R_{2+3}
straight or nearly so, forming about a 75°
angle with R_{4+5}. Petiole of cell M_1 one-half
longer than r-m cross vein. Cubital cell
slightly narrowed at apex. Genitalia charac-
terized by strong lateral lobes of ninth sternum
and small claspers shaped as in Figure 21*a*.
Ninth tergum nearly divided into two plates
(Fig. 21*b*).

Length: Body, 5.0–6.0 mm.; wings, 6.0–7.0 mm.

TYPE LOCALITY: Cairns, Queensland.

Type in the Macleay Museum, Sydney.

I have seen specimens from Australia, in the British Museum, which had been determined by Dr. F. W. Edwards.

Plecia palauensis Hardy

Plecia palauensis Hardy, 1956, Insects of Micronesia Diptera: Bibionidae and Scatopsidae 12(2): 88, fig. 1a–d.

This is a dark-brown to black species but the genital characters show relationship to *P. javensis* Edwards (with the thorax entirely rufous). As in *javensis* the claspers are joined by a narrow sclerotized bridge, the ninth sternum is very broad, the median portion of the sternum is narrow, and the posterior lateral margins are acutely pointed (fig. 4, Hardy, 1952, Beitr. z. Ent. 2(4–5): 431). It differs from *javensis* and from other known

FIG. 21. *Plecia ornaticornis* Skuse. *a,* Ninth sternum; *b,* ninth tergum.

Plecia by the details of the male genitalia (as shown in Hardy, 1956, *loc. cit.,* fig. 1c, d) and as described below; by the dark coloration; by the 6-segmented flagellum of the male antenna (rather than 8); also by the normally developed ocellar triangle, not greatly reduced as in *javensis*.

MALE: Predominantly opaque brown to black, bases of halteres yellow. A moderately deep furrow is present down each dorsocentral line and a faint indication of a median furrow is present on the anterior half of the mesonotum. The wings are evenly fumose and vein R_{2+3} is almost vertical in position. The ninth tergum is deeply cleft, almost to its base, on the hind margin; the lateral lobes are gradually tapered and obtuse at apices (*loc. cit.,* fig. 1c). The posterior lateral margin of the ninth sternum is produced into rather elongate, slender lobes which extend beyond the apices of the claspers; through the median portion the sternum is very narrow, measured longitudinally it is less than half as long as a clasper. The claspers are simple, obtuse at apices, with a partially developed secondary lobe on the lateral margins, and with a narrow sclerotized bridge connecting them on their inner anterior margins (*loc. cit.,* fig. 1d). For further details refer to the original.

Length: Body, 3.0–3.8 mm.; wings, 3.8–4.5 mm.

Female unknown.

TYPE LOCALITY: Garakayo Is., Palau Islands. It is known only from the Palau Islands, Eastern Caroline Islands.

Type in the Bernice P. Bishop Museum.

Plecia parva Malloch
Fig. 22a–c

Plecia parva Malloch, 1928, Linn. Soc. N. S. Wales, Proc. 53: 606.

A rather small species in the group of species which have the mesonotum chiefly rufous and the pleura brown to black. It is distinguished from all other known species of *Plecia* by the peculiar development of the male
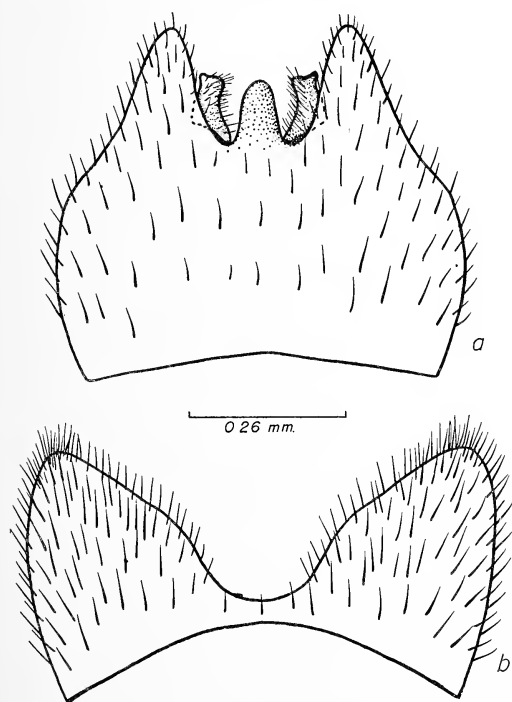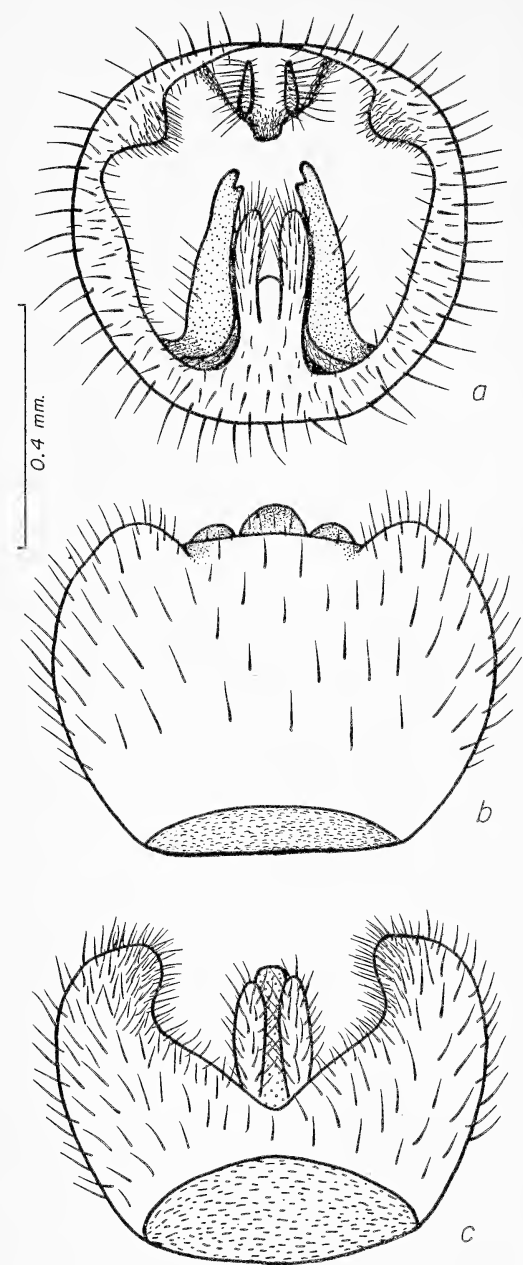
FIG. 22. *Plecia parva* Malloch. *a*, Genitalia, end view; *b*, ninth sternum; *c*, ninth tergum.

genitalia. The ninth segment is fused into a ring which forms a capsule surrounding the genitalia (Fig. 22*a*).

Malloch placed this in the *fulvicollis* complex but the specimens I have seen have the

pleura brown to black, the front half of the mesonotum is discolored with brown to black with the hind portion rufous, also the scutellum is rufous. In the female the front of the mesonotum is not so extensively darkened. The antennae are broken on the specimens at hand, Malloch said the antennae are 8-segmented, exclusive of the minute tip. Legs stouter than usual, femora moderately swollen, tibiae almost parallel sided. Wings pale brown. Vein R_{2+3} slightly curved, forming a 65° angle with R_{4+5}. Petiole of cell M_1 not quite one-half longer than r-m cross vein. Cell Cu not narrowed. The ninth tergum and sternum are fused on the sides and form a capsule around the internal genital structures. The claspers and the shape of the hind margin of the sternum cannot be seen clearly except in end view (Fig. 22*a*). From a ventral view only, the bases of the claspers are visible (Fig. 22*b*). The tergum is moderately cleft on the hind margin (Fig. 22*c*).

Length: Body, 4.0–4.5 mm.; wings, 5.0–5.5 mm.

TYPE LOCALITY: Los Banos, Philippine Islands.

Type in the U. S. National Museum.

I have studied specimens from Luzon, P. I.

Plecia ruficornis Edwards
Fig. 23

Plecia ruficornis Edwards, 1927, Treubia 9: 363.

This species is known only from the type male and its exact position is not clearly understood. Edwards' description was very brief and his drawing of the genitalia is not entirely clear. It is indicated that the lobes on the posterior lateral margins of the sternum are slender, sharply pointed and widely spaced, that a broad rounded median lobe and a pair of small submedian lobes are also present on the hind margin of the sternum (Fig. 23). The ninth tergum has a deep U-shaped cleft on the hind margin, the lobes are subacute at apices.

This fits in the *fulvicollis* complex by having the thorax entirely rufous. It apparently is

closest related to *P. ornaticornis* Skuse, from Australia, but is differentiated by the pointed widely separated lateral lobes of the sternum, the presence of the submedian lobes, and by the rounded claspers.

Length: Body and wings, 4.0 mm.

TYPE LOCALITY: Kei Island.

Type in the British Museum (Natural History).

Figure 23 of the ventral aspects of the genitalia is reproduced from a sketch made of the type by Mr. Paul Freeman of the British Museum.

Plecia rufilatera Edwards
Fig. 24

Plecia rufilatera Edwards, 1927, Spolia Zeylanica 14: 119, fig. 1.

A chiefly black species characterized by having the sides of the mesonotum dull red and the scutellum reddish with a dark median line. Legs and abdomen all black. Wings brown, stigma darker than the remainder of membrane. R_{2+3} nearly straight and nearly vertical. Costa extending almost halfway from tip of R_{4+5} to M_{1+2}. Halteres black. Genitalia as shown in Figure 24, copied from Edwards. "Ninth tergite deeply emarginate, lobes

FIG. 24. *Plecia rufilatera* Edwards. Genitalia, dorsal view, copied from original.

strongly produced; sides of sternite also greatly produced; claspers minute."

Wing length: 6.5–7.5 mm.

TYPE LOCALITY: Nuwara Eliya, Ceylon.

Type in British Museum (Natural History). Known only from the type and allotype.

Plecia siamensis Hardy

Plecia siamensis Hardy, 1951, Rec. Indian Mus. 50: 100, figs. a, b.

A moderate sized species of the *fulvicollis* complex (thorax entirely rufous) and distinguished by the very characteristic male genitalia. It fits closest to *P. subvarians* Walker, from Indonesia, but the ninth tergum is small compared to the sternum and the cleft on the hind margin of the tergum is narrow, its width is only one-fifth to one-sixth that of the segment. The ninth sternum has slender, curved, acuminate lateral lobes and rather broad rounded submedian lobes; the latter separated by a U-shaped cleft extending about one-third the length of the segment, measured in line with the submedian lobes. The claspers are obtuse at apices. See original for a more complete description and figures.

Length: Body and wings, 6.0 mm.

TYPE LOCALITY: Koh Chang Is., Siam.

FIG. 23. *Plecia ruficornis* Edwards. Ninth sternum from sketch by Paul Freeman.

Type in the British Museum (Natural History).

Plecia subvarians Walker
Fig. 25a, b

Plecia subvarians Walker, 1857, Linn. Soc. London, Proc. 1: 105.

This species fits in the *fulvicollis* complex by having the thorax entirely opaque orange to rufous. It is closest related to *P. siamensis* Hardy and is distinguished by the male genital characters. The ninth tergum is much stronger and extends to or beyond the apices of the sternum and the cleft in the middle of the hind margin of the tergum is broadly V-shaped and about one-third as wide as the segment (Fig. 25a). The submedian lobes on the hind margin of the sternum are pointed on the inner side just below the apices and are separated by a cleft which is sometimes expanded at the bottom (Fig. 25b). In *siamensis* the median cleft on the ninth tergum is rather narrow, the submedian lobes of the sternum are rounded and are separated by a U-shaped cleft. The posterior lateral lobes of sternum are slender, very slightly curved and the claspers are broad and blunt.

The male antennae possess 9 segments and the female 11. The wings are light brown fumose, darker along the costal margin. Vein R_{2+3} is bent rather sharply at base and enters the costa at about a 55° angle to vein R_{4+5}. The petiole of cell M_1 is one-half longer than the r-m cross vein. Vein Cu_1 is bent sharply downward near the apex, the apical portion of the cubital cell is about equal to the length of the m-cu cross vein.

Length: Body, 5.5–6.0 mm.; wings, 6.5–7.0 mm.

TYPE LOCALITY: Sarawak, Borneo.

Type in the British Museum (Natural History).

It has been recorded from Sumatra, Java, Ceram, and Singapore. Brunetti (1912, Fauna of Brit. India, Diptera Nematocera, p. 163) recorded *subvarians* from India as a synonym of *P. fulvicollis* (Fabricius), this is an error. I have seen the type and other specimens from Borneo.

Plecia sundaensis Hardy

Plecia sundaensis Hardy, 1952, Beitr. z. Ent. 2(4–5): 432–434, fig. 5a, b.

This species is related to *P. subvarians* Walker and to *P. siamensis* Hardy because of the development of the male genitalia. It is readily differentiated by the very deep, broad cleft on the hind margin and by the sharp pointed lateral lobes of the ninth tergum (*loc. cit.*, fig. 5a); by the more evenly tapered, sharp pointed lateral lobes and by the more slender submedian lobes of the ninth sternum (*loc. cit.*, fig. 5b). Also the hypopleura of *sundaensis* are brown to black and a small brown spot is present on the upper portion of each mesopleuron; rather than the pleura be-
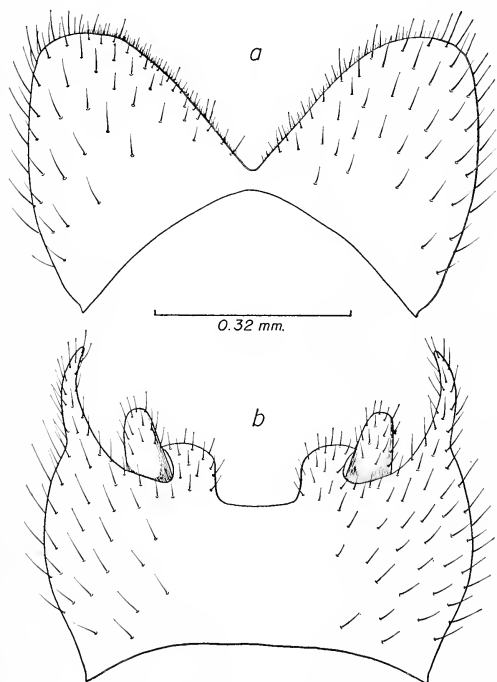
FIG. 25. *Plecia subvarians* Walker. *a*, Ninth tergum; *b*, ninth sternum.

ing entirely rufous. The ninth tergum is cleft nearly to its base by a broad **U**-shaped concavity on the hind margin; the cleft is broader than each of the lateral lobes. The claspers are about two times longer than wide and are gradually tapered to a subacute apex.

For a more complete description and figures refer to the original.

Length: Body, 5.5 mm.; wings, 7.0 mm.

TYPE LOCALITY: West Flores, Lesser Sunda Islands.

Type in the Deutsches Entomologisches Institut, Berlin.

Plecia tenebrosa n. sp.
Fig. 26*a, b*

Related to *P. erebea* Skuse, from Australia, but the male genitalia are very different, as shown in Figures 26*a* and 10*a*.

MALE: A moderately large predominantly dull-black species. *Head:* Antenna reddish

brown, with only seven distinct segments, the last two are closely joined. Mouth parts rather elongate, their length is about equal to the height of the head. Ocellar tubercle large, prominent. *Thorax:* Largely black humeri rufous, pleura and metanotum tinged with rufous in the ground color. Knobs of halteres black, stems brownish red. *Legs:* Dark brown to black, tinged with red; densely black haired. Segments slender. *Wings:* Light brown fumose, stigma slightly darker than the remainder of membrane. Vein R_{2+3} slightly curved, nearly vertical and almost meeting tip of R_1 at wing margin. The costa extends about one-third the distance between the tips of veins R_{4+5} and M_{1+2}. *Abdomen* and *genitalia:* Dark brown to black, all pile black. The ninth tergum is rather gently concave on hind margin, the concavity extending only about one-third the length of the segment (Fig. 26*b*). The ninth sternum is slightly wider than long, the posterior lateral margins are rounded and are produced just a short distance beyond bases of claspers; the posterior median margin has a rather sharply pointed lobe. The claspers are rather large, simple, pointed at apices (Fig. 26*a*).

Length: Body, 8.0 mm.; wings, 8.7 mm.

Female unknown.

Holotype male and three paratypes "Java coll. Winthem." In the Naturhistorisches Museum, Wien under the name *"fulvicollis."*

Type and one paratype returned to Vienna. One paratype in the Bernice P. Bishop Museum and one in the University of Hawaii collection.

Plecia tergorata Rondani
Fig. 27*a–c*

Plecia tergorata Rondani, 1875, Ann. del Mus. Civ. di Storia Nat. di Genova 8: 462.

Plecia karnyi Edwards, 1927, Treubia 9: 363, fig. 3a, b. New synonymy.

Edwards' figure 3b of *P. karnyi* would seem to differ from *tergorata* by not having the claspers of the male joined and by the claspers being

0.6 mm.
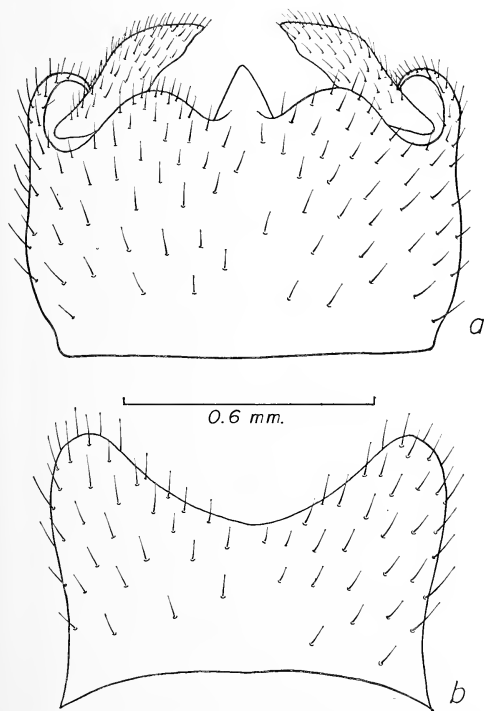
FIG. 26. *Plecia tenebrosa* n. sp. *a*, Ninth sternum; *b*, ninth tergum.
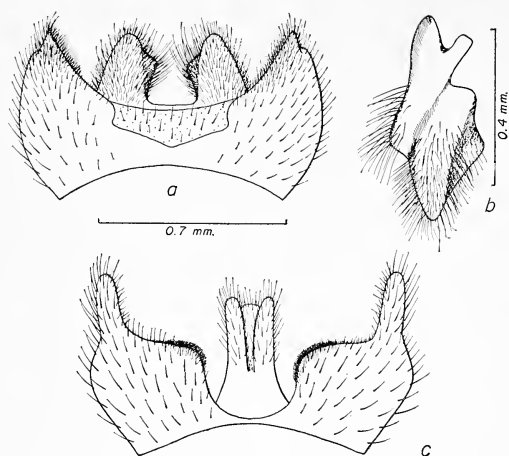
FIG. 27. *Plecia tergorata* Rondani. *a*, Ninth sternum; *b*, right clasper, end view; *c*, ninth tergum.

more slender and pointed as seen from a ventral view. I have studied in detail a specimen from W. Java which compared with Edwards' type in all respects. The claspers are joined and the difference in shape seems to be due to orientation. I see no way to distinguish these.

Plecia tergorata has not been recognizable from the literature. Brunetti (1912, Fauna of British India, Diptera Nematocera, pp. 164, 165) obviously was wrong in recording (redescribing) it from India. Speaking of the specimens before him from northern India, he said "there can be no doubt of their identity with this species." His assumptions, however, were based entirely upon color and antennal characters and his conclusions would have applied just as well to more than a dozen other species.

This fits in the complex which has the mesonotum rufous and the pleura brown to black. The male genitalia show relationship to *P. javensis* Edwards (*fulvicollis* complex) by having the claspers joined at bases; the structures are, however, quite differently developed, the claspers lack the long apical lobe and the rod-shaped accessory structures at sides of the aedeagus are also lacking.

Male antennae almost entirely dark brown to black, tinged with yellow on the scape and

pedicel; 9-segmented with the apical 2 rather closely fused. Ocellar tubercle prominent. Mesonotum and scutellum all rufous except for a tinge of brown on the front portion of the former. Pleura entirely brown to black. Halteres brownish yellow. Legs brown, tinged with rufous in the ground color of the femora. Tibiae and tarsi nearly straight sided, not swollen. Wings brown fumose, vein R_{2+3} oblique, entering the costa at about a 60° angle to R_{4+5}. The ninth sternum is about two times broader than long, acutely pointed at posterior lateral margins, and largely membranous on the posterior median portion. The claspers extend as far as apices of sternum, are joined at bases by a narrow sclerotized bridge; the apices are rounded and a subacute point is present on inner margin, as seen from dorsal view (Fig. 27*a*). From an end view the clasper is bilobed at apex, with a rounded apical lobe and a narrower, truncate subapical lobe on outside margin (Fig. 27*b*). The ninth tergum is two times broader than long, deeply cleft on the hind margin, and with the posterior lateral margins developed into slender lobes, rounded at apices (Fig. 27*c*).

Length: Body and wings (male), 5.5–6.0 mm.

TYPE LOCALITY: Borneo.

Type in the Museo Civico di Storia Naturale, Genova, Italy.

I have studied the type female and the series of 2 ♀ ♀ and 3 ♂ ♂ labeled "Giava Teibodas (this may possibly be spelled Tejbodas), Ott 1872, O. Beccari." They were evidently the specimens studied by Rondani and are probably paratypes. The details of the genitalia given above and the figures are based upon one of these males, kindly loaned to me by Dr. Delfa Guiglia of the Museo Civico di Storia Naturale, Genova. Edwards (1931, Tijdschr. v. Ent. 74: 279) recorded it from Sumatra and said it was much like *karnyi* Edwards. I have also seen specimens from Brastagi, Calgdris, Sumatra, Aug. 1924, in the British Museum (Natural History).

Plecia tjibodensis Edwards

Plecia tjibodensis Edwards, 1927, Treubia 9: 363,
    fig. c.

A moderately small species belonging in
the group of species which have the thorax
rufous above and brown to black on the pleura.
It seems most closely related to *P. tergorata*
Rondani and *dubia* Edwards and is distinguish-
ed by having a rather shallow cleft on the hind
margin of the ninth tergum, extending about
one-third the length of the segment; rather
than the cleft extending nearly to its base.
Also the claspers terminate in a slight point at
their outer apices. From Edwards' figure it ap-
pears that the sternum is about three times
wider than long, the posterior lateral margins
are rounded and there is apparently no median
lobe on hind margin. It appears that the
aedeagus is rather well developed, extending
nearly to apex of sternum and has a small
accessory structure on each side. Refer to
loc. cit., figure c.

Length: Body, 3.5–4.0 mm.; wings, 5.0 mm.
TYPE LOCALITY: Tjibodas, Java.
Type in the British Museum (Natural
History).

I have not studied specimens of this species.

Plecia tridens n. sp.
Fig. 28*a*, *b*

Fitting in the complex of species which
have the thorax all rufous but with strikingly
different genitalia from any of the known
species (Fig. 28*a*, *b*).

MALE. *Head:* Antennae brown, tinged with
rufous on the basal segments; 9-segmented.
Ocellar triangle well developed. *Thorax:* En-
tirely opaque yellow-red except for a faint
black streak at tip of scutellum. Stems of
halteres yellow, knobs brown. *Legs:* Brown to
black, tinged with rufous on the coxae and
bases of femora; segments slender. *Wings:*
Faintly brownish or yellowish fumose, darker
along costal margin. Vein R_{2+3} at about a 75°
angle to R_{4+5}. *Abdomen* and *genitalia:* Entirely
dark brown to black. Ninth tergum cleft
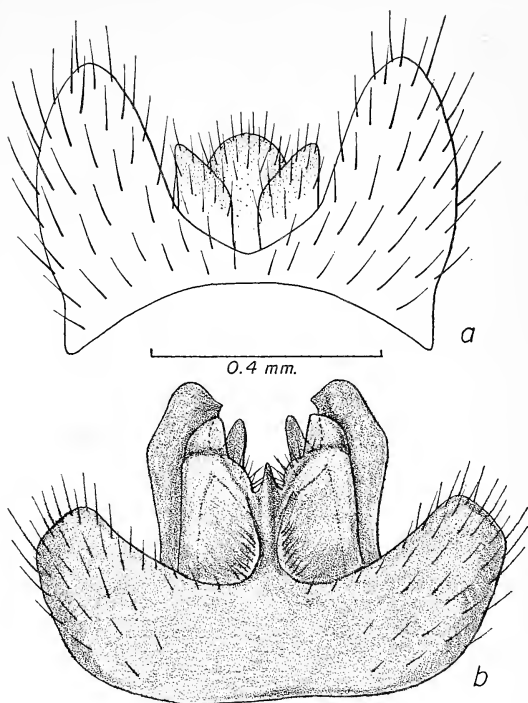
FIG. 28. *Plecia tridens* n. sp. *a*, Ninth tergum; *b*,
ninth sternum.

nearly to its base on the hind margin (Fig.
28*a*). Ninth sternum with a large, heavily
sclerotized, three-pronged projection from the
middle of the hind margin. Claspers large,
heavily sclerotized, each with an acute sub-
apical point, a well-developed basal lobe on
inner margin, and lying directly behind the
projected portion of the sternum (Fig. 28*b*).

Length: Body, 4.0 mm.; wings, 4.4 mm.
Female unknown.
Holotype male, Ins. Wetter, Netherlands
Indies, Acq., 1896 (C. Schädler).
Type returned to the Rijksmuseum van
Natuurlijke Historie, Leiden.

Plecia tristis van der Wulp

Fig. 29*a–c*

Plecia tristis van der Wulp, 1884, Notes Leyden
    Mus. 6: 251.

One male in the Rijksmuseum van Natuur-
lijke Historie, Leiden, from Java appears to be
this species. It is a small, all-black species dis-
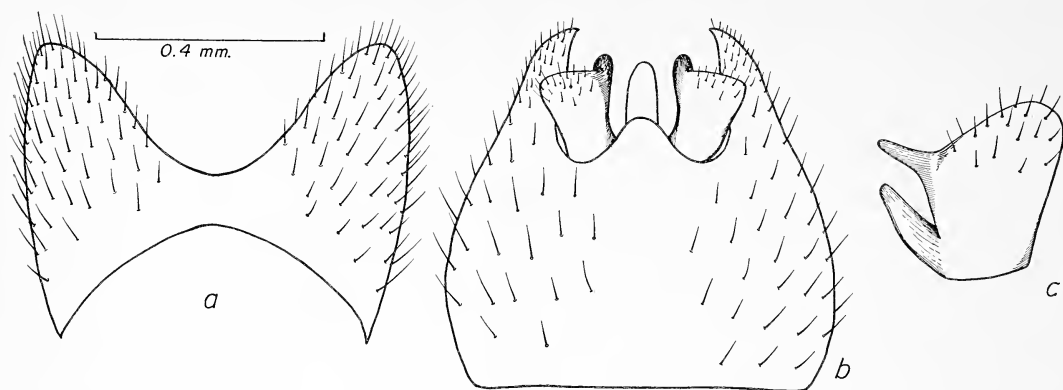
FIG. 29. *Plecia tristis* van der Wulp. *a*, Ninth tergum; *b*, ninth sternum; *c*, inner lateral view of right clasper.

tinguished from other *Plecia* by the male genital characters. The thorax is grayish on pleura and margins of mesonotum, also down the furrows; the areas marked off by the furrows are faintly subshining black. The wings are faint yellow-brown fumose. Vein R_{2+3} is straight and oblique and forms about a 45° angle with vein R_{4+5}. The ninth tergum is deeply concave on the hind margin and the lateral lobes are well developed (Fig. 29*a*). The ninth sternum has a long fingerlike projection from the posterior median margin extending nearly to apices of claspers. The posterior lateral margins of the sternum are developed into a pair of sharp pointed lobes which extend beyond the claspers (Fig. 29*b*). From a direct ventral view the clasper appears blunt and rounded at the apex. As seen from a lateral view (Fig. 29*c*) a pair of dorsally projected lobes are developed.

Length: Body, 4.0 mm.; wings, 5.0 mm.

I have studied one specimen from Goenceng Cedah, Java, Mar. 1911 (Leiden Mus.).

TYPE LOCALITY: Mount Ardjoeno, East Java.

The type is supposed to be in the Rijksmuseum van Natuurlijke Historie, Leiden, Holland, but I was unable to find it when I visited the Museum in August 1954. None of van der Wulp's specimens seemed to be designated and I doubt that the type of *P. tristis* is still extant.

Plecia varians Edwards

Fig. 30*a*, *b*

Plecia varians Edwards, 1928, Jour. Fed. Malay States Mus. 14: 43.

The original description consists of only two lines saying that the species "closely resembles *P. subvarians*, differing only in the male hypopygium, especially in the shape of the claspers," plus a figure from a dorsal view. Edwards' figure is not clear, the claspers are not differentiated from the sternum. It is probable that Edwards mistook the curved lateral lobes of the sternum for claspers, the claspers themselves are not distinctive, but the lobes of the sternum will separate it from related species.

Antennae of male 9-segmented, including the nipplelike tip; the female antennae are 10-segmented. These are all black in the male and tinged with yellow on the first two segments in the female. The front of the female has a predominent orange colored tubercle and a moderately distinct ridge down the middle. Thorax entirely orange to rufous. Legs dark colored, segments all slender. Wings light brown fumose. Vein R_{2+3} straight, forming a 75° angle with R_{4+5}. Petiole of cell M_1 two times longer than r-m cross vein. Cubital cell just slightly narrowed in the male, more strongly narrowed in the female. Ninth tergum

of male two times wider than long with a broad U-shaped cleft in middle of hind margin (Fig. 30*a*). Ninth sternum wider than long with slender, inwardly curved lateral lobes and rather broad, rounded submedian lobes on hind margin, the latter separated by a basally expanded cleft. The claspers are two or more times longer than wide and are obtuse at apices (Fig. 30*b*).

Length: Body, 5.5–6.0 mm.; wings, 7.0–8.0 mm.

TYPE LOCALITY: Pahang, Malaya.

Type in the British Museum (Natural History).

I have studied the type series in the British Museum.

Plecia (Heteroplecia) visenda Hardy

Plecia (Heteroplecia) visenda Hardy, 1950, Hawaii. Ent. Soc. Proc. 14: 75–76, fig. 1a, b.

This is the subgenotype of *Heteroplecia* Hardy which is characterized from other *Plecia* by the absence of ocelli or an ocellar triangle; there are no indications of these structures in

FIG. 30. *Plecia varians* Edwards. *a*, Ninth tergum; *b*, ninth sternum.

0.4 mm.

either sex, and the compound eyes of the male are joined on the front up to the hind margin of the head. The species can be recognized by the subgeneric characters; it is a large species which has the thorax all rufous but the male genitalia are very different from those of other *Plecia* known to me.

MALE. *Genitalia:* The tergum and the sternum are partly fused laterally on the dorsum. The tergum is developed into two large, sometimes divergent, lobes separated by a cordate shaped median cleft (*loc. cit.*, fig. 1a); the lobes are not usually so divergent as was figured, the genitalia of this specimen probably had been flattened. The ninth tergum extends about two times the length of the sternum. The ninth sternum is developed into a large rounded lobe on each posterior lateral margin, these extend nearly three-fourths the length of the clasper; the posterior median margin has a broad, irregular, submedian lobe just inside each clasper, these are separated by a small cleft which has a small median point at its base. The claspers are rather strong, extending well beyond lobes of sternum, and are sharp pointed at apices (*loc. cit.*, fig. 1b).

Length: Body, 9.5 mm.; wings, 11.0–12.0 mm.

The female has not been previously described. It fits the characteristics of the male except for sexual characters. The front is moderately broad, at its narrowest point it is about two-thirds as wide as one eye, measured from dorsal view; the front is subopaque, densely dark gray pubescent with a short keel in middle below, just above antennae and evenly rounded on the upper portion and vertex with no indication of ocelli or an ocellar triangle. The head is almost as high as long, the occiput is scarcely produced. Antennae brown, tinged with rufous especially on the basal segments; 12-segmented, counting the small tip portion. The palpi are elongated, they are one-third longer than the head or the antennae.

Length: Body, 10.0 mm.; wings, 12.0 mm.

TYPE LOCALITY: Mt. Eiori, Dutch New Guinea.
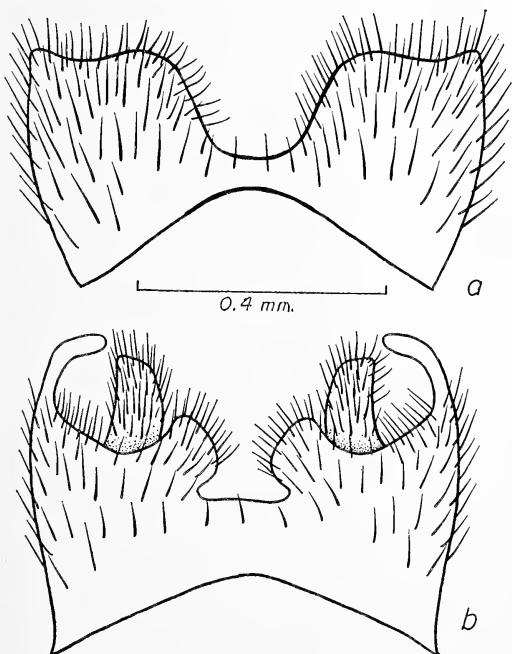
I have since seen a large series from Araucaria Camp, 800 m., Netherlands Indies-American New Guinea Exped., Mar. 1939 (L. J. Toxopeus).

Plecia zamboanga Hardy

Plecia zamboanga Hardy, 1950, Hawaii. Ent. Soc. Proc. 14: 84–85, figs. 9a, b.

A large species fitting in the *fulvicollis* complex because of the entirely opaque yellow to orange thorax. It is closest to *P. fulvicollis* (Fabricius) and is differentiated by the striking differences in the development of the ninth sternum of the male. The claspers are tiny and inconspicuous and are partially fused with the sternum. The broad, heavily sclerotized, median process on the hind margin of the sternum is truncate at apex, rather than being bilobed and the lobes of the posterior lateral margins are very differently developed (as shown in *loc. cit.*, fig. 9b). The ninth tergum is deeply cleft on the hind margin, the lobes are broadly rounded at apices (*loc. cit.*, fig. 9a).

Length: Body, 9.0–9.5 mm.; wings, 10.0–10.5 mm.

TYPE LOCALITY: Zamboanga, Mindanao, Philippine Islands.

Type in the Museum of Comparative Zoology.

Central Pacific Eels of the Genus *Uropterygius,* with Descriptions of Two New Species[1]

WILLIAM A. GOSLINE[2]

IN THE CENTRAL PACIFIC, at least, *Uropterygius* is, after the related *Gymnothorax*, the largest and most difficult genus of eels. Inadequate knowledge precludes any final revision at the present time either of the genus as a whole or of the species in the region under consideration. The individuals are, for the most part, among the smallest and most inconspicuous of morays, and some species doubtless remain undescribed. Nomenclatorially, the final allocation of the older names to the various forms must await examination of the types or of topotypical material. Where the specimens available do not aid in the solution of nomenclatorial problems, I have followed Schultz (1953: 140–159); to do otherwise would only be substituting one dubious name for another.[3]

The basic classification of the genus was laid down by Schultz (1943: 23–33; 1953: 140–159). The present paper could not have been written without this groundwork. It is, indeed, something of an addendum to Schultz's treatments of the genus, and full descriptions and synonymies have been omitted here. Its purpose is to clarify further the distinctions and relationships between Central Pacific species of *Uropterygius*, and to describe two new ones.

The genus, as here recognized, has the limits drawn for it by Schultz (1953: 99), i.e., *Scuticaria* is considered a synonym but *Anarchias* is excluded as a separate valid genus. Within the area under consideration *Uropterygius* may be sufficiently defined as containing those muraenid eels with no lateral-line pore near the posterior nostril, with sharp teeth in the jaws, and with the fins restricted to the tail region. (An alizarin-stained specimen of *U. knighti* shows that in this species, at least, the rayed portions of the dorsal and anal fins commence about one head length ahead of the tip of the tail.) The investigated members of the genus, except *U. xanthopterus*, seem to be differentiated from other muraenids in having a single open lateral-line pore above and before the gill opening. Other morays examined (*Muraena pardalis, Echidna polyzona, E. nebulosa*, various species of *Gymnothorax, Rabula fuscomaculata, Anarchias allardicei, A. cantonensis*, and *A. leucurus*) have two pores, one in front of the other, in this area (as does *Uropterygius xanthopterus*). The one exception is *Echidna zebra*, which does not have any pore.

The type of *Uropterygius* is *U. concolor* Rüppell from the Red Sea.

KEY TO THE CENTRAL PACIFIC SPECIES OF *Uropterygius*

1. Anus in front of or approximately under the middle of the length.............3

   Anus at least two-thirds of the way back along the length. Species reaching at least 3 feet in length.................2

2. Posterior nostril over front border of orbit; color plain brown.......**U. sealei**

   Posterior nostril over eye; color light with prominent round or oval dark blotches..................**U. tigrinus**

3. Anus somewhat in front of middle of length; body without large, round or oval dark blotches.................5

Anus under or slightly behind middle of length; body with large, round or oval dark blotches.....................4

4. Vomerine teeth continuous with those on the premaxillary (Fig. 1*b*) and of approximately the same form; posterior nostril in a tube in specimens over 10 inches long; head without lengthwise bands.................U. polyspilus

Vomerine teeth well separated from the premaxillary series, relatively small, conical; posterior nostril without a tube; head with lengthwise bands. U. fijiensis

5. Gill opening on middle or lower third of sides.............................7

Gill opening high, on upper third of sides. Teeth multiserial on the sides of jaws (Fig. 1*c, d*); eye in front of middle of wide gape.......................6

6. Teeth in a broad band all along the sides of the upper jaw (Fig. 1*c*); head and chin spotted; maximum known length, 17 inches..............U. supraforatus

Teeth in 3 or 4 rows along middle of the upper jaw, tending to become biserial posteriorly (Fig. 1*d*); head and chin plain; maximum known size, 10 inches ....U. fuscoguttatus

7. Teeth on the sides of the jaws in one or two rows; vomerine teeth uniserial or absent; maximum size about 10 inches.8

Teeth on the sides of the jaws in three rows; vomerine teeth in two or three rows in front; maximum size 3 feet.... ....U. marmoratus

8. Teeth on the sides of the jaws in two rows; vomerine teeth present........9

Teeth on the sides of the jaws in a single

row; no vomerine teeth (Fig. 1*e*). Color uniform brown.........U. inornatus

9. Markings of some sort always present.10

Color uniform brown. Inner row of teeth on the lower jaw extending only about two-thirds of the way back along the outer row..............U. concolor

10. A single open lateral-line pore in front of and above the gill opening (for the approximate position of this pore, see Fig. 2); no scattered light punctulations on the head and body................11

Two open lateral-line pores in front of and above the gill opening, one before the other; numerous scattered light punctulations on head and body...... ....U. xanthopterus

11. Posterior nostril over or behind the middle of the eye, which lies over or behind the middle of the gape.............12

Posterior nostril over the front of eye, which lies ahead of the middle of the gape.................U. micropterus

12. Tail more or less pointed, the terminal rays about two eye diameters in length; gape short, contained more than 3 times in the head length (to gill opening).... ....U. makatei

Tail bluntly rounded, the rays at its tip short, less than an eye diameter in length; gape relatively wide, contained fewer than 3 times in the head length....... ....U. knighti

Uropterygius sealei Whitley
Table 1

TYPE LOCALITY: Society Islands. This species was originally described as *Scuticaria unicolor* by Seale; the specific name is said to be preoccupied.

MATERIAL EXAMINED: One specimen from the Honolulu aquarium.

The posterior position of the anus and the plain brown color together are said to be distinctive. The other two plain brown species of *Uropterygius* do not seem to reach more than a foot in length whereas our specimen of *U. sealei* is 3 feet long. The dentition of the available specimen is somewhat mangled. Apparently unknown outside of the Society and the Hawaiian Islands.

Uropterygius tigrinus (Lesson)
Table 1, Fig. 1*a*

TYPE LOCALITY: Society Islands. Several specimens examined from Johnston Island and the Hawaiian chain, 27 to 34 inches in length.

The posterior position of the anus, together with the round black markings on the sides, is distinctive. The great similarity between *U. tigrinus* and *U. polyspilus* will be discussed under the latter species. In tooth pattern, *U. tigrinus* and *U. sealei* are very similar and differ from all other members of the genus. The teeth of the inner maxillary row, those on the vomer, and the larger premaxillary teeth are all subequal in size. The inner maxillary and premaxillary teeth are distinctly separated by a gap which is not much smaller than that separating the vomerine teeth from those on the premaxillary. The mandibular teeth are biserial but the inner row stops short of the front of the eye.

Uropterygius polyspilus (Regan)
Table 1, Fig. 1*b*

TYPE LOCALITY: Tahiti. Two small specimens available from Johnston Island and one 17-inch individual from Honolulu, Hawaii.

The young of this species, up to at least 8 inches in length, may be recognized immediately by the abruptly light snout (yellow in life). However, the 17-inch specimen, which agrees with small specimens in other respects, lacks the light snout; its color pattern is an almost exact duplicate of that of *U. tigrinus*. Indeed the specimen was identified as *U. tigrinus* until the relatively forward position of the anus was noted. (Because of this similarity of color pattern the original description of *U. tigrinus* was checked to see that it did not really represent this species. Fortunately the description states that the anus is two-thirds of the way back along the body, which eliminates this possibility.) However, the dentition
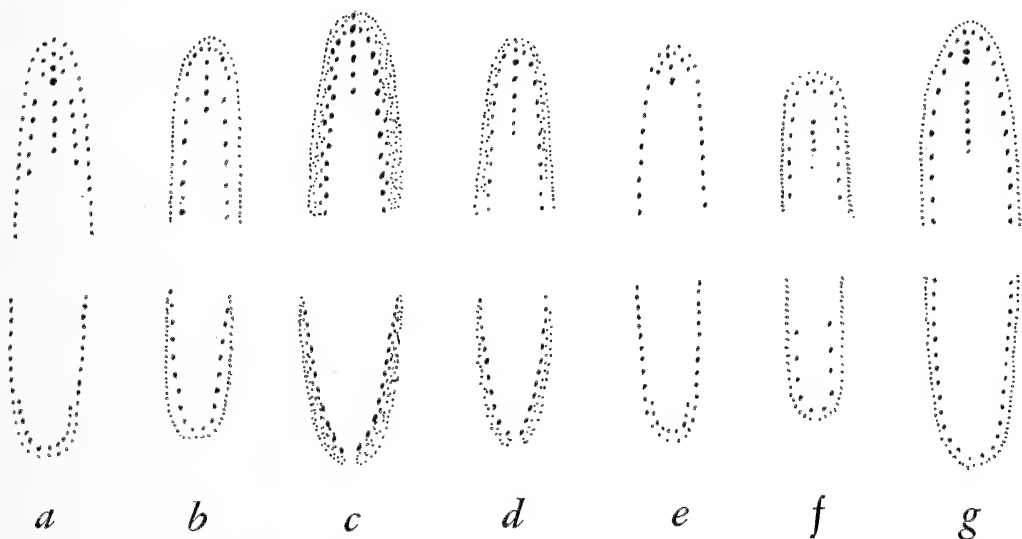
FIG. 1. Diagrammatic representation of dentition of *a, Uropterygius tigrinus; b, U. polyspilus; c, U. supraforatus; d, U. fuscoguttatus; e, U. inornatus; f, U. makatei; g, U. knighti.* Each dot represents a tooth; upper jaw above, lower jaw below.

TABLE 1

Tooth Counts in Certain Species of *Uropterygius*

SPECIES	LOCALITY	LENGTH OF SPECIMEN IN INCHES	TEETH ON ONE SIDE			
			On outer row above[1]	On inner row above[1]	On outer row below	On inner row below
U. sealei.................	Oahu	36	10	10	15	5
U. tigrinus..............	Johnston	27	18	8	17	6
U. polyspilus.............	Oahu	17	35	7	30	8
U. xanthopterus...........	Line Is.	9.5	29	10	23	6
U. micropterus............	Gilberts	9.5	43	15	40	11
U. knighti	Tuamotus	7	29	12	38	8

[1] These counts include both premaxillary and maxillary teeth within the rows indicated.

of the two species is entirely different. In the lower jaw of *U. polyspilus* the inner row of teeth extends about as far back as the outer, and the inner rows on both jaws as well as some of the teeth on the premaxillary and vomer are definitely enlarged and fanglike.

Uropterygius fijiensis Fowler and Bean

TYPE LOCALITY: Fiji. The type and only known specimen has been briefly redescribed by Schultz (1943: 24, 26, fig. 3f).

Judging from the descriptions the salient features of this species are: anus slightly behind middle of length; eye forward of middle of the moderate gape; rear nostril over front border of pupil; color pattern of five or six irregular rows of brown spots, more or less joined, and about eight or nine somewhat broken lengthwise bands on the sides of the head. The bands on the head would appear to be unique among Central Pacific species of *Uropterygius*.

The color pattern is somewhat reminiscent of *U. polyspilus* and *U. tigrinus* but the tooth pattern would seem to place it in an entirely different portion of the genus.

Uropterygius supraforatus (Regan)
Fig. 1c

TYPE LOCALITY: Savaii, Western Samoa.

SYNONYM: *U. dentatus* Schultz, with Johnston Island as type locality. Four specimens, 7 to 16 inches long, examined from the Gilberts, Johnston Island, and Honolulu.

The similarity between *U. supraforatus, U. dentatus,* and *U. fuscoguttatus* has been previously noted (Gosline, 1955: 155). There, in the absence of adequate comparative material, *U. supraforatus* and *U. dentatus* were both provisionally recognized. Subsequent examination of two Gilbertese specimens failed to show any basis for separating the two, which are herewith synonymized.

Schultz (1953) allocates specimens to both *U. supraforatus* and *U. dentatus.* His differentiation of the two species is based on color differences and on a gap between the vomerine and premaxillary teeth in *U. dentatus.* As to this gap, I find it no greater in our Johnston Island specimen topotypic for *U. dentatus* than for the Gilbertese specimens that appear to be typical of *U. supraforatus.* In color, the most significant difference between the Johnston and Hawaiian specimens at hand and those from the Gilberts is the heavier spotting on the former; but these specimens are also larger, and other species of *Uropterygius* also become more heavily pigmented with increasing size.

Uropterygius fuscoguttatus Schultz
Fig. 1d

TYPE LOCALITY: Bikini.

MATERIAL EXAMINED: Numerous specimens from Hawaii and Johnston Island.

About the only differences between this species and *U. supraforatus* seem to be those mentioned in the key. In the presence of

needlelike vomerine teeth far forward, though not in other characters, these two species somewhat resemble *U. sealei, U. tigrinus,* and *U. polyspilus.*

In the Hawaiian Islands this species occurs commonly in about 25 to 75 feet of water, but it was taken at a much shallower depth at Johnston Island, probably because of the very different reef conditions there.

Uropterygius marmoratus (Lacepède)

TYPE LOCALITY: New Britain.

SYNONYM?: *Ichthyophis pantherinus* Lesson. No specimens seen.

Lacepède's original description, based on Commerson, is of a marbled brown and white *Uropterygius,* a meter in length, with needlelike teeth. Lacepède's name has been applied to various members of the genus. Here, it is identified with the species called *Gymnomuraena marmorata* by Weber and de Beaufort (1916: 397, figs. 193, 194) and presumably represented by the larger specimens listed under *Uropterygius marmoratus* by Schultz (1943: 33; 1953: 155). The following combination of characters would seem to be distinctive for this species: large size, anus in front of middle of length, many rowed teeth, and gill openings about halfway up the sides. It would appear to be most similar to *U. supraforatus.*

In recent years Schultz (1943, 1953) has apparently confused two species in his accounts of *U. marmoratus* under the impression (mistaken, I believe) that the teeth and tooth rows increase with age. I can find no support for this supposition in available material of any species of *Uropterygius.*

Uropterygius inornatus new species
Table 2, Figs. 1*e*, 2*a*

HOLOTYPE: U.S.N.M. 175007, 187 mm. total length, off Waikiki reef, Oahu, in 25–35 ft. of water, Dec. 31, 1952, Gosline, Brock, Randall, *et al.*

PARATYPES: University of Hawaii No. 1686, 2 specimens, 108 and 129 mm., with the same data as the holotype; U.H. No. 1788, 1 specimen, 107 mm., cove 1 mi. north of Kailua, Hawaii, in 12–30 ft. of water, June 19, 1953, Brock, Gosline, *et al.*; U.H. No. 2362, 2 specimens, 117 and 189 mm., ½ mi. off Hawaiian Village, Waikiki, in 25–30 ft. of water, Sept. 7, 1951, Herald, Harry, Brock, Gosline, *et al.*

A very slender eel, heaviest just behind the head, and distinctly smaller near the tail (see Table 2). Caudal fin rays extending at least one eye diameter beyond the tip of the last vertebra.

The posterior nostril has no raised rim and opens above the middle of the eye; there is no lateral-line pore near it. The eye lies nearer the corner of the mouth than to the tip of snout, but the gape extends at least an eye diameter behind the eye. The usual lateral-line pores are present on the head, but on the jaws there are only 5 (sometimes 4 or 3) pores on each side instead of the usual 6. A single open lateral-line pore is present in front of and above the gill opening, as is normal for *Uropterygius.* The gill opening lies slightly above the midline of the sides.

The teeth are uniserial on the sides of the mouth. The only needlelike teeth are a few at the front of each jaw. There are no vomerine teeth in any of the six specimens.

The color is a plain, uniform brown though the tip of the tail and the chin are a lighter brown.

The uniserial teeth on the sides of the jaws and the absence of vomerine teeth in this species seem to be unique for *Uropterygius.* The closest relative of *U. inornatus* appears to be *U. concolor* Rüppell. (Certain counts and measurements of the only available specimen of the latter species, from Onotoa in the Gilbert Islands, are given in Table 2 for comparison.) *U. concolor* exactly duplicates *U. inornatus* in color, but appears to be a stockier, longer-headed eel with vomerine teeth and with a second, inner row of larger teeth running at least two-thirds of the way back in each jaw.

The name is derived from the Latin word *inornatus,* meaning undecorated.

Uropterygius concolor Rüppell

Table 2

TYPE LOCALITY: Red Sea. One specimen from the Gilberts examined, slightly less than 5 inches long.

This is one of three plain brown species of *Uropterygius* known from the Central Pacific. From *U. sealei* it differs in the more anterior position of the anus and in having the small, conical, vomerine teeth widely separated from the fanglike teeth of the premaxillary. *U. inornatus* does not have any vomerine teeth at all. Dental pattern in *U. concolor* is about as in Figure 1*f*; tooth counts and measurements for the available specimen are given in Table 2.

Uropterygius xanthopterus Bleeker

Table 1

TYPE LOCALITY: East Indies. Numerous specimens available from the Line, Tuamotu, and Marshall Islands.

Uropterygius xanthopterus is unique among available forms of the genus in having the usual two muraenid, but not *Uropterygius*, lateral-line pores above and ahead of the gill opening. The light speckling on a dark ground is equally distinctive. The tooth pattern is about as in Figure 1*f*.

Uropterygius micropterus (Bleeker)

Table 1

TYPE LOCALITY: East Indies. Schultz (1953: 156) considers *U. tinkhami* Fowler, type locality, Carolines, as a synonym of this species.

MATERIAL EXAMINED: One specimen, 9 inches long, from the Gilberts.

Judging from the specimen available, the forward position of the nostril and eye noted in the key are better distinguishing characters for this species than the color pattern; the vomerine teeth are biserial in front as shown in Schultz's figures and not uniserial as stated in his description (1953: 156). Except for the biserial vomerine teeth, the dentition is about as in Figure 1*g*.

TABLE 2

CERTAIN COUNTS AND MEASUREMENTS IN THREE SPECIES OF *Uropterygius*

Measurements, aside from total length and height of gill opening, expressed as thousandths of the total length

	U. inornatus		U. concolor	U. makatei (Holotype)
	Holotype	Five paratypes		
Total length (mm.)	187	107–189	123	230
Greatest depth	46	33–38	53	63
Depth at anus	34	30–37	47	50
Depth one head length before tail	24	20–28	35	40
Distance from tip of snout to anus	448	428–463	448	438
Head length, measured to gill opening	88	77–88	119	147
Tip of snout to corner of mouth	33	28–33	42	37
Snout length	20	16–22	20	19
Eye diameter	7	5–7	11	7
Distance from eye to corner of mouth	13	7–14	13	20
Length of middle caudal rays	9	6–9	7	13
Height of gill openings, in per cent distance up sides	50	58–67	58	20
Tooth counts				
Outer row above, on one side[1]	12	16–19	27	23
Inner row above, on one side[1]	2	0–4	8	9
Outer row below, on one side	13	14–20	28	25
Inner row below, on one side	3	2–5	4	5
Median teeth on premaxillary	3	2–3	3	3
Median teeth on vomer	0	0	7	4

[1]These counts include both premaxillary and maxillary teeth within the rows indicated.
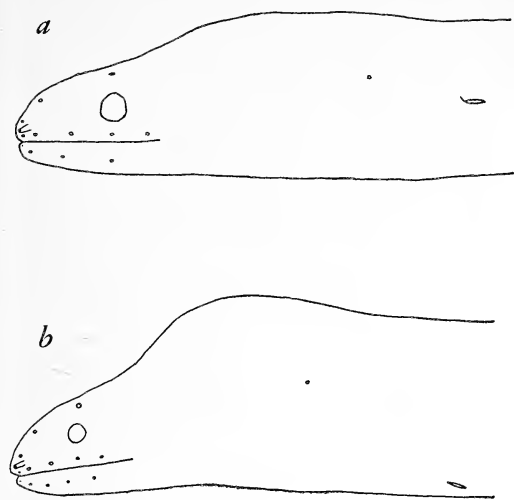
FIG. 2. Heads of holotypes: *a, Uropterygius inornatus; b, Uropterygius makatei.*

Uropterygius makatei new species

Table 2, Figs. 1*f*, 2*b*

HOLOTYPE: (Only known specimen.) U.S. N.M. 175008, 230 mm. in total length, taken just west of the phosphate dock, Makatea, northern Tuamotus, over reef flat and in surge channel, Mar. 15, 1956, by John E. Randall.

A short-jawed, heavy-headed, stocky *Uropterygius*. The tail is bluntly pointed with the terminal rays well developed for the genus.

The posterior nostril has a rudimentary rim and opens above the middle of the eye; there is no lateral-line pore near it. The small eye lies over the middle of the gape which is very short, contained almost four times in the head length. The usual lateral-line pores of the genus are present. The gill opening is very low, almost ventrally directed.

The teeth in the inner maxillary, premaxillary, and mandibular rows are moderately enlarged and fanglike. The vomerine teeth are smaller and essentially similar in size to those on the outer rows of the jaws.

The ground color is light with brown reticulations darkest on the snout and back, present on the mandible and lower surface of the body

posteriorly, and almost completely lacking on the belly, which is plain gray. The anterior nostril and the head pores are of the same color as the surrounding areas, but the posterior nostril has a rather narrow white rim.

Uropterygius makatei seems to have shorter jaws in relation to the head length than any of the others taken up here. It also has the gill openings lower on the sides. This latter character places it with *U. knighti* in the key, but it has more of the look and coloration of *U. micropterus.* This last species has far longer jaws and more numerous teeth than *U. makatei,* however. In tooth pattern, the new species belongs with *U. concolor* and *U. xanthopterus.*

Named *makatei* for the island at which it was taken.

Uropterygius knighti (Jordan and Starks)

Table 1, Fig. 1*g*

TYPE LOCALITY: Samoa.

SYNONYM: *Uropterygius reidi* Schultz with type locality, Tau Island, Samoan group. Two specimens from the Tuamotus and one from Wake Island seem typical of the species; innumerable specimens from Hawaii, the Tuamotus, and Wake are provisionally identified with it.

The last section of Schultz's key (1953: 143, section 22b) seems to require comment. It leads to two species: *U. necturus* (Jordan and Gilbert) from the Gulf of California, and *U. knighti* (Jordan and Starks). Now according to Jordan and Evermann (1896: 404) *U. necturus* has "a pore situated just above the posterior nostril." If this is so, *U. necturus* is not a *Uropterygius* at all but an *Anarchias.* As for *U. knighti*, it is keyed by Schultz as having the "lower jaw notably barred or reticulated with brown"; however, Jordan and Starks' figure (in Jordan and Seale, 1906: 205, fig. 10) shows the whole lower jaw unpigmented and their description states that the mandible is white below. If this is true, there is little left to dis-

tinguish *U. knighti* from *U. reidi,* and I believe the two are synonyms.

At present I am also allocating to *U. knighti* a whole series of more or less dark-chinned specimens. It is presumably this type of fish that Jordan and Evermann (1905: 111) and innumerable others have been calling *U. marmoratus* and which is probably represented by the small specimens in Schultz's (1943: 33; 1953: 155) accounts of the same species. The reasons for provisionally combining the dark-chinned and light-chinned forms (cf. Schultz, 1953: 159) are: (1) that I can find no valid morphological differences between them, (2) that available collections (from Makatea, Wake) that contain the light variety also contain the dark one, and (3) that many individuals are partially intermediate between the two.

That the dark form is not the young of *U. marmoratus* can be more convincingly demonstarted: of the hundreds of Hawaiian specimens many are ripe adults but the largest is just over 13 inches long; in specimens from 3 to 13 inches there is no evidence for additional tooth rows with increasing size.

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Structure and Reproduction of *Cottoniella hawaiiensis* n. sp. (Rhodophyta)[1]

Maxwell S. Doty and
M. Ruth Wainwright[2]

While sorting over fine red algae washed onto the beach at Kailua, Oahu, Hawaiian Islands, the junior author discovered an alga which appears to be representative of a previously undescribed specific taxon to be placed in the genus *Cottoniella* for reason of its obvious similarities to *Cottoniella arcuata* Boergesen, the type of that genus. Accordingly, this newly found material is described here as:

Cottoniella hawaiiensis n. sp.

Figs. 1–9

Thalli 2 cm. longi, ramis sterilibus polystichis ad 130 μ diametro et a 4 cellulis pericentralibus cinctis, cellula apicale 10–12 μ diametro in serie segmentis discoideis transversalibus partita, segmentis deinde 4 cellulis pericentralibus ferrentibus, ramis endogenis a apicibus cellulis centralibus productis et eis stichidiis tetrasporangialibus vel ramis vegetativalibus a ramo parenti simulantibus formantibus, ramis haplostichis determinatis ex angula ventrali anteriori cellulae lateralarum pericentralarum ferrentibus, stichidiis tetrasporangialibus jugum sporangiarum tetrahedro-partitarum ferrentibus, loculis sporangialibus ad 74 μ longa et ad 60 μ diametro.

The specimens were pale pink and, when disengaged from the other polysiphonous algae in which they were floating entangled, could be separated into lax unilateral branch systems up to about 2 centimeters tall (Fig. 1). The principle branches are up to 130 microns in diameter. The species is known only from the type collection (M. Doty No. 13,582) made November 13, 1955 by the junior author. The type is deposited in the Bernice P. Bishop Museum with isotypes in the herbaria of the senior author, the New York Botanical Garden, the University of California (UCM-132664), and the University of Adelaide (21,100).

It is to be noted (Figs. 2, 6) that the arching of the branches begins distad of the appearance of branch initials in *C. hawaiiensis* and appears to be correlated with elongations of the first pericentral cell produced. This characteristic of the branches is much like that figured by Silva and Cleary (1954: 252, fig. 15) for *Platysiphonia parva*.

The bases of the apical cells of the young endogenous branches, which are the only branches that become corticated, are about 10 microns in diameter. The bases of the apical cells of the principle axes are often 12 microns in diameter.

The discoidal segments cut off from the apical cells of the main branches elongate until they are at least one-third of their diameter in length (Figs. 2, 5, 6). They then produce abaxially first a dorsal pericentral cell (Figs. 6, 7). At this time there are usually two discoid cells between that which bear this first pericentral cell and the apical cell. It appears that the pericentral cells to the right and left of the dorsal first pericentral cell are the next

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FIG. 1. Sketch of a major branch system showing branch curvature, positions of branches of different kinds, and relative diameters. The largest of the four major branches shown was about 0.5 cm. in length.

to be produced. The fourth pericentral cell is cut off opposite the first and from about the fifth segment removed from the apical cell. Collections of *Cottoniella arcuata* made by A. J. Bernatowicz in Bermuda (53-380 and 53-96) show a similar sequence of pericentral cell development. This is in contrast to what Boergesen (1930: 146) says is true of his *C. fusiformis* from the Canary Islands.

The endogenous branches arise (Figs. 5, 7) from the anterior ventral surfaces of segments in front of or at the corner of the ventral peri-

central cells. An endogenous branch on a segment is somewhat parallel to any exogenous branch that may be on the same segment. Endogenous vegetative branches develop entirely like the parent axis and (as in *C. arcuata*) curve toward the parent axis in their development. The lateral pericentral cells on vegetative branches were seen in no case to divide other than in the production of exogenous branches. In more basal parts of the thalli, the longest branches of this sort are up to 675 microns long.
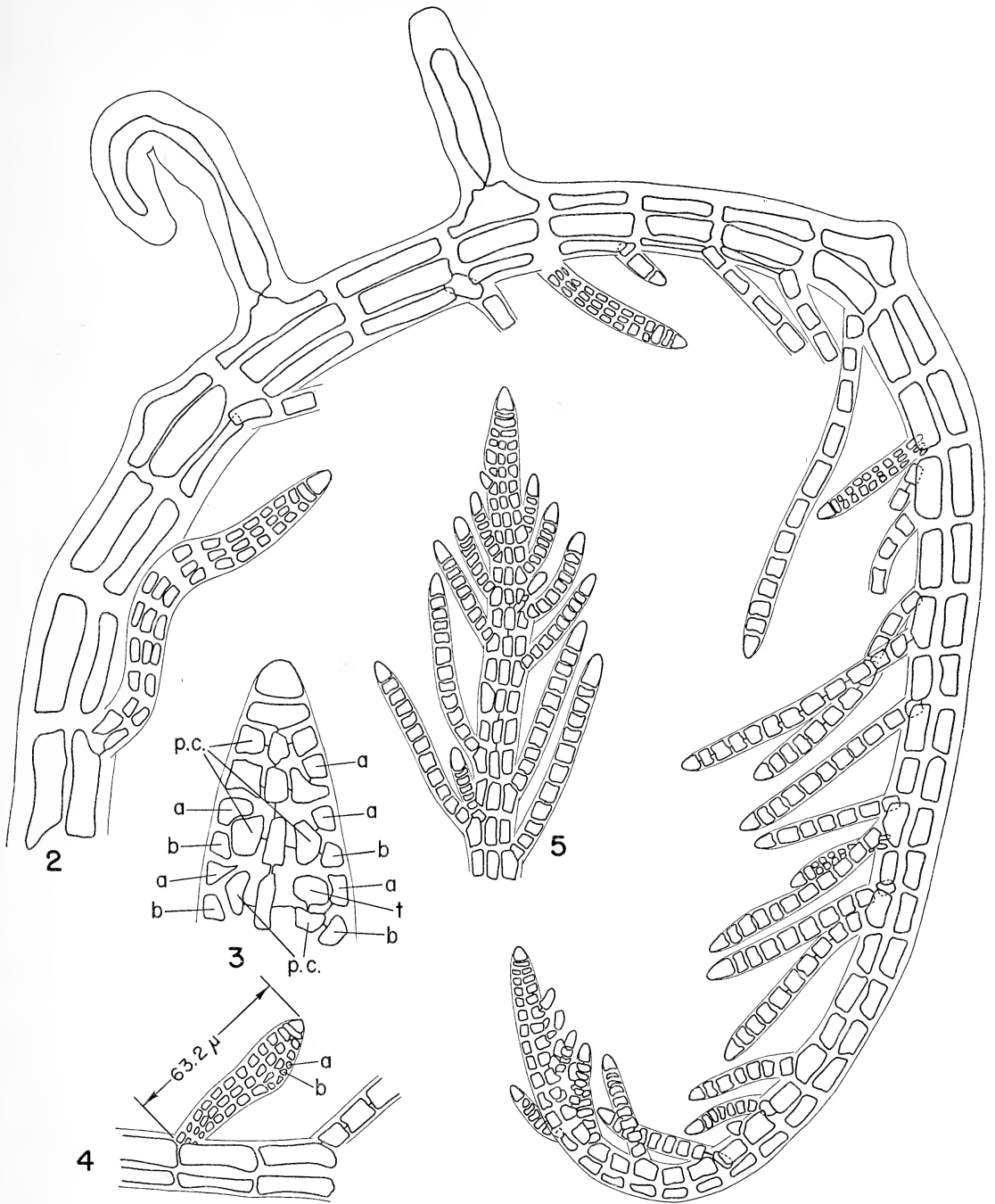
FIGS. 2–5. (2) Cellular detail of one indeterminate branch to show relationships of size and position of ultimate branch kinds and their origins in part. (3) Ventral view of tetrasporangial stichidium apex. Neither dorsal nor ventral pericentral cells shown. (4) Young tetrasporangial stichidium. (5) Cellular detail of indeterminate branch apex from ventral view. Neither dorsal nor ventral pericentral cells shown.

Exogenous monosiphonous branches appear on about the sixth or seventh segment removed from the apical cell (Figs. 2, 5). Boergesen's figure (1919: 336, fig. 335) shows the monosiphonous branches as arising at about the tenth to fourteenth segment in his species, *C. arcuata*. With Bermuda materials of *C. arcuata*, provided by A. J. Bernatowicz, we have been able to confirm this observation. Boergesen also describes and figures the monosiphonous branches as arising on the convex side of the branch endogenously. In the Bernatowicz collections cited, the tips curve and the branches appear on the convex side, the branches then become reflexed or curved in the other direction so that at maturity the branches do indeed protrude from the concave surface.

These uncorticated exogenous branches are about 20 microns in diameter and, while the basal cell hardly becomes more than twice its diameter in length, the other proximal cells of these ultimately 14- to 16-celled branches become up to 5 times as long as broad (Figs. 1, 2). The cells of the distal portion of these more or less determinate branches become progressively shorter distally until they are, just beneath the apical cell, discoid in immature branchlets with hemispherical apical cells, or elongated and tapered toward the slender conical apical cell of a mature branchlet.

The basal cells of the uncorticated exogenous branches are attached by their primary pit to the anterior-ventral corner of a lateral pericentral cell. They occur alternately on the right and left lateral pericentral cells of successive segments (Fig. 5). Secondary pits are formed in abundance between this basal cell and at least the lateral pericentral cell in the next anterior segment (Fig. 8). At least one of these secondary pits may be unusually large (see Fig. 8).

The older exogenous branches apparently drop off as the axes develop. Boergesen (1919: 147, fig. b) notes that exogenous branching was very rare in *C. fusiformis*. He illustrates them, however, as exogenous at least once. According to Papenfuss (1944: 207), of the Delesseriaceae, only *Taenioma* and *Caloglossa* have exogenous branches. On this point our organism seems to be more rhodomelaceous than delesseriaceous.

The rhizoids are exogenous and appear several segments posterior to the level at which endogenous branches appear (Figs. 1, 2, 8). They do not appear until after the other branches have appeared. They appear only from dorsal pericentral cells in our material. Sometimes a segment will bear one of each of the three types of branch. The rhizoids (Figs. 2, 8) become separated from the parent pericentral cell (Fig. 2) at an early age and may become a few cells in length (Fig. 8). There is a tendency for the rhizoids to be curved. Their tips become a disc of rows of small, crowded cells, connected by pits, that in some instances seem to have arisen by sympodial development (Fig. 8). In at least one case this pad was stuck to the *Polysiphonia* with which it was found entangled.

The tetrasporangial stichidia arise endogenously in the same positions as do endogenous vegetative branches and appear to take their place. The discoid segments cut off by the apical cell of the stichidium usually elongate to about one third of their diameter before cutting off a pericentral cell (Figs. 3, 4, 9). This usually occurs at the level of the first or second discoid cell. The first pericentral cell appears to be either dorsal or ventral; each situation was found with about equal frequency. Only a few rather disarranged branches were available for study of this point, however. The other three pericentral cells appear very rapidly and are usually present on the second or third discoid central cell segment.

The younger pairs of tetrasporangia arise towards the apex of the stichidium (Figs. 3, 9). The lumen of the tetrasporangium is radially elongated at least to a length of 60 microns at maturity, while the diameter parallel to the stichidial axis is about 47 microns. The tetraspores (Fig. 9) are tetrahedrally arranged.

The lateral pericentral cells each serve as

FIGURES 2,4,5 & 9
50 μ

FIGURES 3,6,7 & 8
50 μ
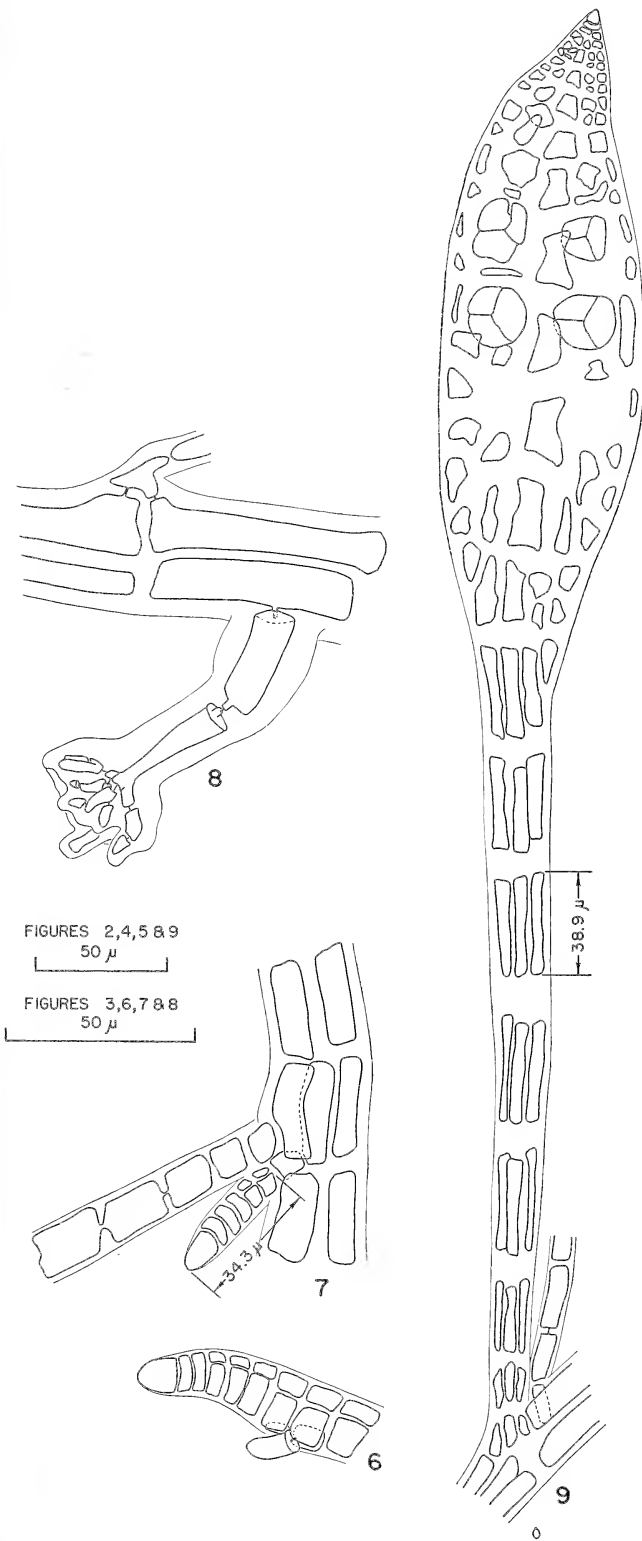
FIGS. 6–9. (6) Indeterminate branch apex from lateral view. Central cells not shown beyond third cell below apex, ventral pericentral cell not shown in lowest segment. (7) Cellular details of young indeterminate branch. (8) Cellular details of mature rhizoid and of an exogenous determinate branch basal cell. (9) Outline of mature tetrasporangial stichidium which had shed the contents of two sporangia.

tetrasporangial mother cells (Fig. 3*pc*). They produce two "cover" cells (*a* and *b* in Figs. 3, 4) (apical and basal), the tetrasporangium (Fig. 3*t*), and finally a third cover cell somewhat basally. The first two laterally produced cover cells curve around over the tetrasporangium. The third is produced ventrally and, likewise, grows over the surface of the sporangium. Thus the two pericentral cells (dorsal and ventral) and the three cover cells cut off by each of the two lateral pericentral cells at each side (i.e., 8 cells in all) make up the outer layers of each fertile mature stichidial segment.

DISCUSSION

Since "cortication" in our material consists, in sterile regions, only of pericentral cells, the opinion becomes critical as to whether or not there are "flanking cells" or "cover cells" present, cut off by the pericentral cell before the tetrasporangium. If there are flanking cells, one is inclined to consider *Cottoniella hawaiiensis* a member of the Delesseriaceae, accepting Papenfuss's (1944: 202) statement that, in that family, cover cells are cut off only after the tetrasporangium.

Certainly one "weakly-covering" cell is cut off *after* the tetrasporangium, and the lateral pericentral cells produce two cells lateral to themselves *before* the tetrasporangium is produced in the same way the flanking cells are produced in *Platysiphonia*.

The tetrasporangia are somewhat more covered over in *C. hawaiiensis*, and by a more complicated cover cell system, than in the case of *Taenioma* (Papenfuss, 1944: 195, figs. 4, 14, 199) or *Platysiphonia* (Silva and Cleary, 1954: e.g., 256, fig. 27), and other similarly simple members of the Ceramiales. However, the stichidial features are shown here for *Cottoniella* and for tetrasporangial areas of other genera, by various authors elsewhere, to be quite homologous in structure. Schotter has emphasized already (1951: 287) the similarity between the vegetative structure of *Cottoniella* and these two other genera. Especially are

Cottoniella and *Platysiphonia* similar in basic vegetative structure.

As regards the sequence of pericentral cell formation, it is interpreted as rhodomelaceous in all the *Cottoniella* material we have seen, following Naegeli's (1847, fide Schotter) early distinction of this family from the Delesseriaceae on this point. Boergesen's figures (1919: 147, fig. 59b, c) lead us to expect this in *C. fusiformis*, despite his statements to the contrary.

All in all it appears that *Cottoniella* is one of those simple algae that would some time ago have been placed in the Sarcomenioideae (Sarcomenieae of authors). The flattened four pericentral-celled nature of the stichidia of *C. hawaiiensis* bearing two tetrasporangia per segment bespeak of a delesseriaceous affinity for *Cottoniella*, and we are inclined to relegate it at present to that family but recognize its possible connecting-link nature between that family and the Rhodomelaceae.

SUMMARY

Study of tetrasporic *Cottoniella hawaiiensis*, a previously undescribed species from Hawaii, indicates placement of this genus among the Delesseriaceae on the basis of the mode of tetraspore production, or intermediately between that family and the Rhodomelaceae on the basis of weighting and interpretation of other features such as flanking cells, cover cells, apical cell development, and exogenous branches. The appearance of exogenous branches as a regular feature and the degree of development of the pericentral cell systems set the Hawaiian species apart from all others in this genus.

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Further Notes on *Felisacus* Distant
(Heteroptera; Miridae; Bryocorinae)

T. E. Woodward[1]

IN AN EARLIER PAPER (Woodward, 1954) the author reviewed the species groups of *Felisacus* and described and redescribed some of the included species. Since then, additional material has accumulated of *elegantulus* (Reuter) and *filicicola* (Kirkaldy); in the present paper, further locality records are given and additions made to the descriptions, with a more complete account of the range of variations and of the nature of the specific differences. A new species, *F. dauloi*, is described from the highlands of New Guinea. The female valvulae of the three species are described and figured; it is hoped that as further descriptions become available these will provide additional criteria for the separation of species groups. The ovarian eggs of *elegantulus* and the male genitalia of *filicicola* are figured for the first time.

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ELEGANTULUS Species Group

Felisacus dauloi n. sp.
Figs. 1a; 2e, f

STRUCTURE: (Holotype female.) Head across eyes 1.32 times median length (0.67:0.51); interocular space of vertex 1.85 times width of eye (0.32:0.17). Base of head forming a cylindrical collum separated from rest of head by an annular constriction; collum 0.81 times as wide as head immediately behind eyes (0.38:0.47) and 0.57 times head across eyes; width behind eyes 0.70 times width across eyes. Rostrum 1.20 mm. long, reaching to middle of mesosternum. Antennae with segment I cylindrical, not swollen subbasally; II, 1.26 times as long as I (1.35:1.07); III, 1.50 times I (1.60:1.07); IV, 0.56 times I (0.60:1.07); I, 0.95, and II, 1.20 times basal width of pronotum.

Pronotum in mid-line 1.84 times as long as head (0.93:0.51); 1.21 times as wide posteriorly as long (1.13:0.93), 2.64 times as wide as across anterior collar (1.13:0.43), and 1.69 times as wide as head across eyes; shape and punctation of pronotum as in *elegantulus*, except that posterior margin is somewhat more deeply excavated.

Hemelytra greatly surpassing abdomen, costal margin of corium 2.43 times as long as pronotum (2.27:0.93) and 3.15 times as long as cuneus (0.72).

Genitalia: First (mesial) valvulae with apex subacute; apical dorsal teeth large. Second valvulae with apex subacute; portion below sclerotized ridge abruptly narrowed before
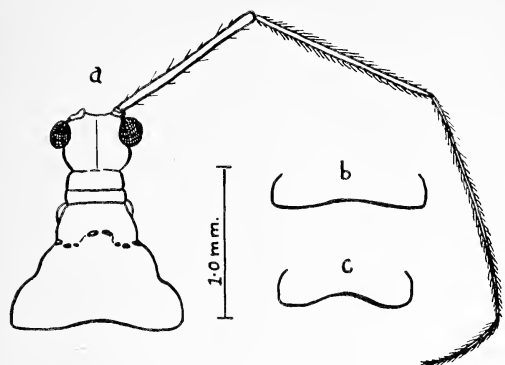
FIG. 1. a, *Felisacus dauloi* n. sp., female, head and pronotum; b, *Felisacus elegantulus* (Reuter), female, posterior margin of pronotum; c, *Felisacus filicicola* (Kirkaldy), female, posterior margin of pronotum.

apex; translucent portion above ridge in form of a subtriangular lobe, considerably narrowed shortly before apex.

Length: 5.1 mm.; width across hemelytra, 1.25 mm.

The measurements given above in parentheses are in millimeters.

COLOUR: Head, thorax, abdomen, and first antennal segment shining fulvous; apex of first antennal segment tinged with reddish brown, second segment blackish brown with reddish tinge, third and fourth black; eyes dark; type female with a fine red line between and above level of antennifers; type female without trace of infuscations on pronotal shoulders; rostrum brown; abdomen tinged with green. Scutellum very pale and less shining fulvous, darker brown along margins. Legs pale yellowish brown; apices of femora and bases of tibiae darker and tinged with red; rest of femora slightly tinged with green; second and third tarsomeres infuscated. Hemelytra with veins yellowish brown, somewhat infuscated at basal angle of cell, along anal vein and posterior margin of clavus, narrowly along costal margin of corium, and very narrowly around margin of membrane; a short sooty band on corium at apex of claval suture; rest of corium and membrane colourless, transparent (membrane with the usual rugulose surface, iridescent in reflected light); clavus slightly more opaque.

HOLOTYPE FEMALE: Daulo Pass, Central Highlands, New Guinea, *ca.* 8,000 ft., August 20–22, 1956, sweeping ferns in rain forest, T. E. Woodward. Named for place of collection. Deposited in Queensland Museum.

F. dauloi most nearly resembles *elegantulus* (Australia and New Zealand) and is much more closely related to it than to the one other known New Guinea species, *nigricornis* Poppius, described from the lowlands of Huon Gulf. Quite likely *dauloi* is a relict species persisting in the highlands of New Guinea after their separation from the more southerly regions of Australia. The close resemblance between *dauloi* and *elegantulus* becomes apparent from a comparison of the figures given above with those tabled below. The main differences are those of size, notably the greater total length of *dauloi*, its wider head, longer head, pronotum, hemelytra, and first three antennal segments. But in almost all proportions, including those by which *elegantulus* differs from the closely related *filicicola*, the specimen of *dauloi* falls within or almost within the known range of the former species. The only exception in the table is the ratio of the width behind the eyes to the width across the eyes. The rostrum is proportionately shorter than in *elegantulus* and the posterior margin of the pronotum rather more deeply excavated. The valvulae of the female differ as figured. In colour *dauloi* is very similar to the pale form of *elegantulus*, but the first antennal segment is paler.

From *filicicola* the new species differs in its greater size, including width of head and pronotum at base and length of head, pronotum, hemelytra, and third antennal segment; the paler colour; the different ratios for width of pronotum: width of head, antenna III: I, antenna I: width of pronotum, antenna II: width of pronotum, posterior: anterior width of pronotum; the differently formed valvulae.

From the other species of the *elegantulus* group *dauloi* differs notably as follows: from *nigricornis* Poppius in the larger size, paler colour (particularly of head, pronotum, scutel-

lum, clavus, and first antennal segment), relatively shorter pronotum and rostrum, longer second antennal segment in proportion to first; from *jacobsoni* Poppius in the greater size, head without brown crossbar, paler pronotal base, first antennal segment and hemelytra, the nonrugulose crown, the longer third antennal segment relative to second, the relatively shorter pronotum; from *ochraceus* Usinger in the greater size, paler cuneus and inner clavus, relatively smaller eyes, pronotum broader at base in proportion to length of antennal segments I and II, corium longer in proportion to pronotum; from *amboinae* Woodward in the much greater size, paler colour (particularly of first antennal segment and hemelytra), the relatively shorter rostrum, the proportionately longer third antennal segment, the narrower eyes in proportion to vertex, the pronotum wider at base in proportion to anterior collar, the corium longer in proportion to pronotum; from *adamsi* Carvalho in the greater size, different colour (especially paler first antennal segment), relatively shorter rostrum, relatively longer second antennal segment, relatively narrower eye in proportion to vertex.

Felisacus elegantulus (Reuter, 1905)

COLOUR: Of the two main colour forms (Woodward, 1954), only 2 of 20 males and 2 of 12 females from Australia are of the second type (extensive red coloration on head; prothoracic shoulders not or scarcely infuscated). This form appears to be much less prevalent than in New Zealand, where it is represented by three-fifths of the specimens examined. There does not seem to be any correlation between colour and season.

GENITALIA. *Male:* The claspers (Fig. 3c, e) are redrawn for comparison with those of *filicicola*, since previously (Woodward, 1954; fig. 5) they were drawn *in situ* on the pygophor. *Female:* (Fig. 2a, b) First (mesial) valvulae narrowly rounded at apex. Second valvulae more narrowly rounded at apex than in *filicicola*, much less so than in *dauloi*; dorsal trans-
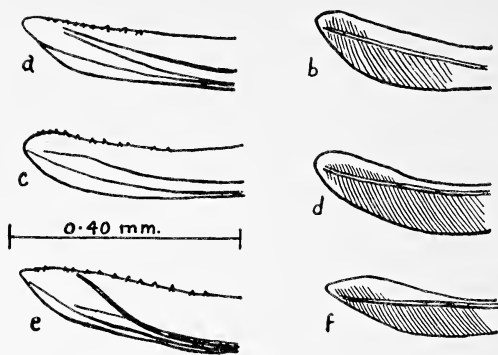
FIG. 2. Female genitalia, *elegantulus* group. *Felisacus elegantulus* (Reuter): a, Apex of first (mesial) valvula; b, apex of second valvula. *Felisacus filicicola* (Kirkaldy): c, Apex of first valvula; d, apex of second valvula. *Felisacus dauloi* n. sp.: e, Apex of first valvula; f, apex of second valvula.

lucent flange broader than in either of these species. The valvulae figured are of an Australian specimen, but those of New Zealand females are similar in all respects.

OVARIAN EGGS: (Fig. 3f) Short ellipsoid, slightly curved; opercular end indented as shown; length 0.60 mm., width 0.35 mm. From a female taken at Barrington Tops, New South Wales, December 22, 1954.

ADDITIONAL RECORDS: Australia, South Queensland, Carnarvon Gorge, 4 males, 2 females, May 29, 1954, *T. E. Woodward*; Lam-
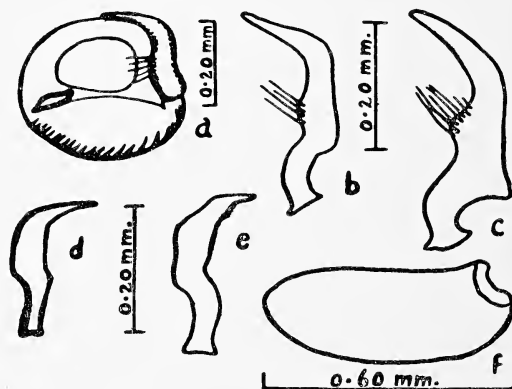
FIG. 3. *Felisacus filicicola* (Kirkaldy), male: a, Pygophor and claspers, posteroventral; b, right clasper; d, left clasper. *Felisacus elegantulus* (Reuter): c, Right clasper; e, left clasper; f, ovarian egg.

TABLE 1
COMPARISON BETWEEN *F. elegantulus* AND *F. filicicola*

	F. elegantulus		*F. filicicola*	
	Male	Female	Male	Female
Head, width across eyes	0.53–0.59	0.55–0.63	0.56–0.60	0.57–0.60
Head, median length	0.37–0.44	0.37–0.45	0.36–0.43	0.39–0.44
Width, interocular space of vertex	0.24–0.29	0.25–0.31	0.25–0.28	0.27–0.29
Width of eye, dorsal	0.14–0.16	0.15–0.17	0.15–0.16	0.15–0.17
Width of head behind eyes	0.38–0.44	0.40–0.47	0.39–0.41	0.40–0.44
Width of collum	0.32–0.35	0.34–0.39	0.31–0.33	0.33–0.35
*Length, antennal segment I	0.73–1.00	0.76–1.00	1.00–1.11	1.01–1.07
Length, antennal segment II	0.89–1.24	0.99–1.22	1.11–1.33	1.13–1.27
Length, antennal segment III	1.29–1.47	1.21–1.48	1.20–1.43	1.17–1.36
Length, antennal segment IV	0.47–0.60	0.55	. . . .	0.44–0.49
Length of rostrum	1.07–1.27	1.17–1.33	1.07–1.13	1.07–1.19
Pronotum, median length	0.65–0.80	0.68–0.85	0.63–0.73	0.63–0.73
*Pronotum, basal width	0.83–0.98	0.90–1.12	0.79–0.87	0.87–0.92
Pronotum, width of anterior collar	0.36–0.40	0.37–0.43	0.35–0.37	0.36–0.40
Corium, length (costal)	1.49–1.83	1.68–2.07	1.53–1.64	1.65–1.73
Cuneus, length (external)	0.53–0.63	0.60–0.67	0.52–0.63	0.57–0.61
Width (maximum across closed hemelytra)	0.91–1.01	1.04–1.20	0.92–1.01	0.99–1.13
Total length	3.6 –4.3	3.9 –4.7	3.6 –3.9	3.9 –4.2
Ratios				
Width vertex: width eye	1.63–2.00	1.69–2.00	1.66–1.82	1.60–2.05
Head, width: length	1.32–1.48	1.31–1.41	1.36–1.56	1.33–1.50
*Width, behind: across eyes	0.70–0.75	0.71–0.76	0.68–0.71	0.69–0.73
*Width, collum: across eyes	0.58–0.62	0.60–0.65	0.55–0.57	0.56–0.60
Width, collum: behind eyes	0.78–0.86	0.82–0.87	0.77–0.83	0.79–0.83
*Width, pronotum (basal): head	1.55–1.66	1.58–1.76	1.39–1.50	1.52–1.59
Length, pronotum: head	1.63–1.90	1.70–1.91	1.53–1.83	1.64–1.80
Antenna II:I	1.16–1.29	1.14–1.30	1.05–1.20	1.12–1.25
†Antenna III:I	1.33–1.58	1.48–1.60	1.08–1.29	1.14–1.34
*Antenna IV:I	0.54–0.64	0.59–0.72	. . . .	0.43–0.48
†II: basal width pronotum	1.08–1.27	1.03–1.19	1.33–1.54	1.27–1.38
†I : basal width pronotum	0.89–1.02	0.84–0.93	1.22–1.41	1.12–1.17
Width pronotum, posterior: anterior	2.27–2.47	2.39–2.63	2.19–2.40	2.30–2.45
Pronotum, basal width: length	1.21–1.31	1.24–1.33	1.17–1.33	1.20–1.33
Length, corium: pronotum	2.20–2.65	2.29–2.54	2.14–2.46	2.27–2.41
Length, corium: cuneus	2.79–3.19	2.63–3.10	2.47–3.00	2.72–2.92

*Useful supplementary characters, which separate most individuals of one species from most individuals of the other.
†Characters that appear to be good distinguishing features

ington Plateau (Lower Ballunjui Falls), October 30, 1955, 1 male, *T. E. Woodward*; Brisbane, 4 males, 2 females, 1954, *T. E. Woodward*. New South Wales: Barrington Tops, 2 males, 2 females, December 22, 1954, *T. E. Woodward*.

SEASONAL OCCURRENCE: Adults have been recorded from South Queensland in January, March, May, June (early), October, and December (i.e., in all seasons except winter) and from New Zealand (where less extensive collecting has been done) in January, February,

and April. Late instar nymphs have been collected in Queensland in January and June and in New Zealand in January and February.

CORRIGENDUM: In Woodward (1954: 43), 11th line from bottom of first column, the word "width" should read "length," as the figures would indicate.

Felisacus filicicola (Kirkaldy, 1908)

COLOUR: All the Samoan specimens noted below differ in some respects from the description of two Fijian specimens given by the

author (1954): a more or less distinct narrow red line between and above level of antennifers (absent in one female); antennal segment I more or less infuscated brown or reddish brown except for pale base; each side of base of pronotum more or less extensively fuscous or black; tibiae and apex of femora red above; cuneus yellow, a red or reddish-brown band bordering cell (entirely yellowish-brown in one female); abdomen red or reddish brown above and at apex. From Kirkaldy's note on coloration (1908: 377) it is evident that the same or a very similar colour form also exists in Fiji. Within the author's experience, *filicicola* can always be distinguished at sight from *elegantulus* by its darker and often more reddish appearance.

GENITALIA. *Male:* Claspers very similar to those of *elegantulus*, but differing in proportions as shown. Right clasper (Fig. 3b) with outer subbasal angle less strongly produced; apical half more abruptly curved. Left clasper (Fig. 3d) more abruptly and more evenly curved toward apex. *Female:* (Fig. 2c, d) First (mesial) valvulae broadly rounded at apex. Second valvulae more bluntly rounded than in either *elegantulus* or *dauloi*; dorsal translucent flange narrower than in *elegantulus*, not subtriangular as in *dauloi*.

ADDITIONAL RECORDS: Western Samoa, N. Upolu, Malololelei, 2,000 ft., 2 males, July 30, 1954, *R. A. Cumber;* 3 males, 2 females, January 19, 1956, *R. A. Cumber;* 3 males, 3 females, January 19, 1956, *T. E. Woodward;* Afiamalu, 2,100 ft., 1 male, 2 females, January 6, 1956, *T. E. Woodward*.

Because of the closeness of *filicicola* and *elegantulus* to each other and to *dauloi*, a de-

tailed comparison has been made and the results are tabulated below. The measurements are based on 17 specimens of *filicicola* (9 males and 7 females from Samoa; 1 female from Fiji) and 54 specimens of *elegantulus* (23 males and 10 females from Australia; 8 males and 13 females from New Zealand). Measurements are in millimeters.

The figures show the considerable intraspecific range and the near correspondence or wide overlap between the species for many of the values. The wider range of measurements now available for these two species also allows more critical comparison with species which are represented by or have been described from one or a few individuals.

Filicicola was described by Kirkaldy (1908) as a variety of *elegantulus* and raised to specific rank by Knight (1935). In redescribing *filicicola* (Woodward, 1954), I listed it as a distinct species but in discussing the species groups considered it not unlikely that it might eventually prove to be a subspecies of *elegantulus*. With the additional data available I am now reasonably convinced of its specific distinctness.

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Culex (Culex) iyengari n. sp., a New Species of Mosquito (Diptera, Culicidae) from the South Pacific

P. F. Mattingly and J. Rageau[1]

THIS IS A MEMBER of the *Culex pipiens* series of Edwards (1932:208) and of a rather well-defined subgroup of that series which may be termed the *Culex trifilatus* subgroup. The species included in this subgroup share with *Culex pipiens* the strongly bent ventral arm of the male phallosome (Fig. 1v.a.) but differ from it in the more strongly developed outer division of the dorsal arm, which is here termed the basal arm (Fig. 1b.a.), and in having the tip of the inner division of the dorsal arm characteristically modified (Fig. 1d.a.). This last modification is, however, less strongly marked in the Pacific species, other than *C. pervigilans*, than in those found elsewhere. *C. pacificus* (Fig. 1b) is remarkable in exhibiting spicules on the ventral arm of the phallosome which are reminiscent of some of the banded-legged members of subgenus *Culex*.

In addition to *C. iyengari* the group includes *C. pervigilans* Bergroth from New Zealand, *C. pacificus* Edwards from New Hebrides, *C. trifilatus* Edwards from East and South Africa and the Cameroons, *C. tamsi* Edwards from the island of Sao Thome in the Gulf of Guinea, the northern Palaearctic *C. torrentium* Martini, and the eastern Palaearctic *C. vagans* Wiedemann. It thus furnishes a good example of a Palaearctic group having a southward extension down the East African highlands into South Africa and another, further east, into the Australasian region. It is entirely absent from the intervening Oriental region except for some penetration into the northwest corner by *C. vagans* (Barraud, 1934: 418). The occurrence of members of the group in the Cameroons and in the Gulf Islands exemplifies the East African element in the Cameroons fauna which is a familiar feature of many groups.

The occurrence of another member so far south as New Zealand is interesting and there has been an implied suggestion that this is an introduced species. Thus Edwards (1932: 210) tentatively suggested placing the Palaearctic *C. torrentium* in the synonymy of the New Zealand *C. pervigilans*. The idea is given some plausibility by the history of whaling in the New Zealand area during the nineteenth century. A careful examination shows, however, that *C. pervigilans* (Fig. 2c) lacks two of the small modified setae on the subapical lobe of the coxite which are present in *C. torrentium* as in *C. iyengari* and *C. pipiens* (Fig. 2a, d). The style of *C. torrentium* is also distinctly narrower than that of the New Zealand species and it seems best to maintain them as distinct species, especially as the early stages of *C. pervigilans* are not available and have only been inadequately described (Graham, 1929: 221).

C. torrentium breeds readily in barrels and metal tanks and thus certainly gives the impression of a species susceptible to human introduction. There is some reason to believe that it may have been introduced into Great Britain in recent years (Mattingly, 1951: 172). It has previously been thought of as an exclusively northern species but it has recently been found as far south as Devonshire and Dorset (Lever, 1954: 65) and the French Pyrenees (Sicart, 1954: 228).

[2] Since this paper was finished Dr. E. N. Marks has informed us that the undescribed male of the banded-legged *Culex (Culex) miraculosus* Bonne-Wepster (1937) from New Guinea also has a phallosome of the *C. trifilatus* type. We are most grateful to her for this interesting piece of information.
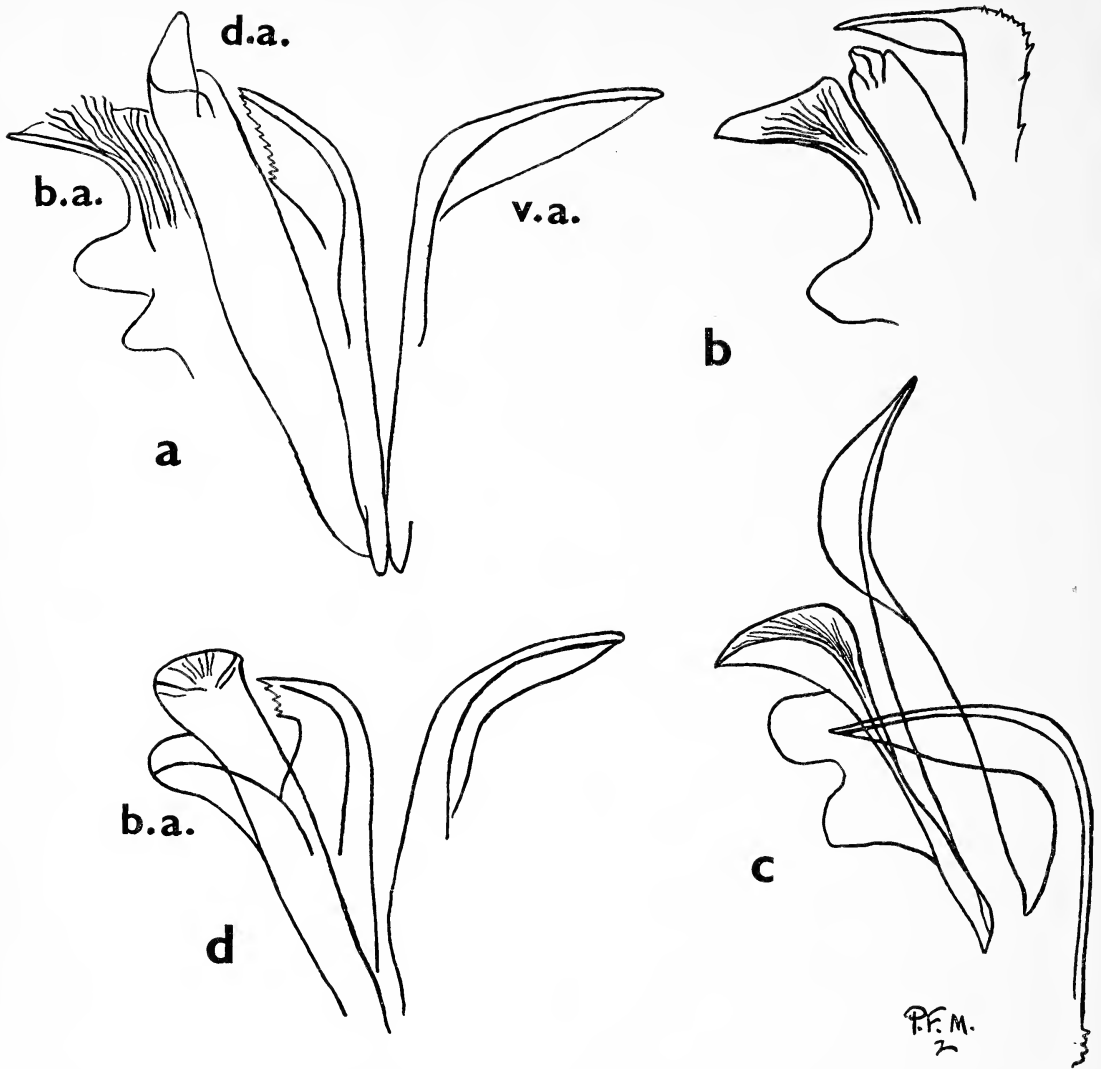
FIG. 1. Male phallosome. a, *Culex iyengari* n. sp.; b, *Culex pacificus;* c, *Culex pervigilans;* d, *Culex pipiens.*

The Devonshire form is unique in possessing postspiracular scales. *C. trifilatus* has appeared previously as an aberrant member of the group in that its larva exhibits supernumerary spines on the siphon distal to the pecten (Hopkins, 1952: 309). Recently, however, a form has been found at Orange Kloof in western Cape Province in which these spines are absent (Muspratt, 1955: 188). On grounds both of morphology and of distribution it seems likely that this is the most primitive of

the Ethiopian forms. An even more southerly *Culex* than *C. pervigilans* has recently been recorded from Auckland Island (Harrison, 1955: 211). It is, however, undescribed and it is not known whether it belongs to the present group.

A comparable distribution to that of the *C. trifilatus* group has been described by Mattingly and Marks (1955) for some members of the subgenus *Neoculex.* Certain of the Mediterranean elements in this subgenus are again
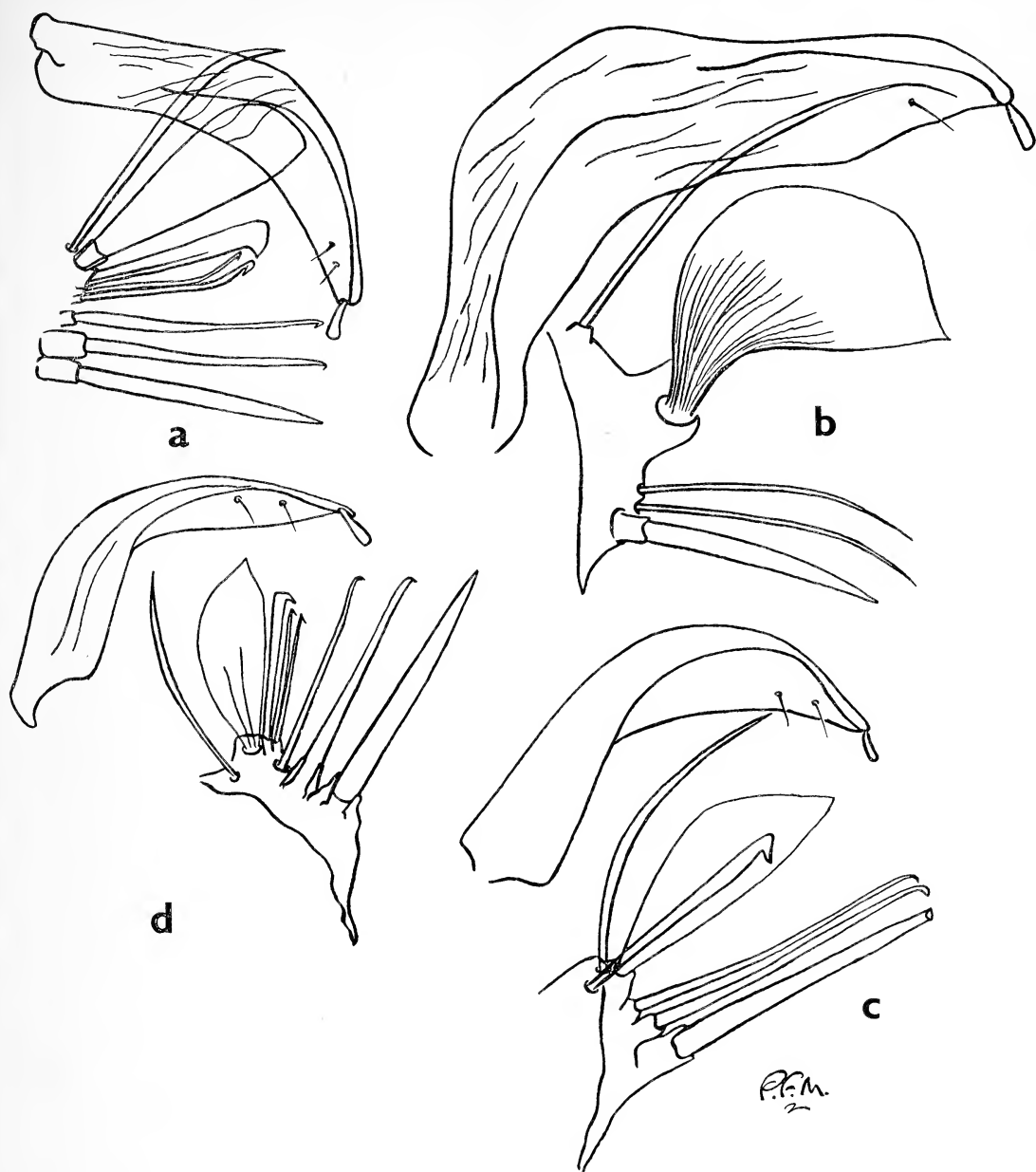
Fig. 2. Male style and subapical lobe of coxite. a, *C. iyengari* n. sp.; b, *C. pacificus;* c, *C. pervigilans;* d, *C. pipiens.*

represented in East and South Africa and in parts of the Australasian region although they are entirely absent from the intervening Oriental region. Other examples are not difficult to find. The subgenus *Ochlerotatus* of *Aëdes* has been discussed by Mackerras (1927, 1950). Apart from minor penetrations in the north-west it is represented in the Oriental region by only a single species. Mackerras' ideas appear to receive some support from recent discoveries in South Africa (Muspratt, 1955: 161) and the Malagasy region (Mattingly and Brown, 1955: 90).

Another group which would probably re-

pay study along these lines is the genus *Theo-baldia*, expecially as the Australian species have been recently revised (Dobrotworsky, 1954).

A description of the new species follows.

Culex (Culex) iyengari n. sp.

The description which follows is based on holotype male from We, Lifu, Loyalty Islands, 7:x:1955, bred out by one of us (J.R.) from a native canoe, allotype female and 4 male and 1 female paratypes with data as for the holotype; 12 male and 4 female paratypes with similar data but bred from a barrel and a tank on 11:x:1955; 5 male paratypes from Baie de la Corbeille, Ile des Pins, New Caledonia, bred out by J.R. from native canoe on 14:xii:1955; 1 male and 1 female paratype from Poncrihuen, New Caledonia, bred out from rainwater in a metal cistern by M. O. T. Iyengar in ii:1956; 2 whole larvae from the same batch as these last 2 adults and a large number of whole larvae from We, Lifu, 8:x:1955 (native canoe) and 9:x:1955 (old barrel and tank), Ba River, near Houailou, 9:vi:1955 (rock pool in stream bed), Hnanemuhaetra, Lifu, 9:x:1955 (hole in coconut trunk), Joj, Lifu, 9:x:1955 (rock pool in coral), Kedany, Lifu (well 38 m. deep) and Kuto, Ile des Pins, 14:xii:1955 (all collect. J. R.). The larvae from We (9:x:1955) were associated with larvae of *Culex pipiens fatigans* (Wied.), *Aëdes notoscriptus* Skuse and *Tripteroides melanesiensis* Belkin, those from Hnanemuhaetra and Joj with larvae of *Aë. notoscriptus* and *T. melanesiensis*, and those from Ba River with larvae of *Culex cheesmanae* Mattingly and Marks and *Culex pipiens australicus* Dobr. and Dr. The holotype and allotype and the bulk of the paratypes will be deposited in the British Museum (Natural History) but some paratypes will be sent to the U. S. National Museum, the Department of Entomology, University of Brisbane and the Institut d'Enseignements et des Recherches Tropicales, Bondy, France.

ADULT MALE: Palps upturned at tip, exceeding the proboscis by about the length of the terminal segment, the hairs on the under surface rather short (Fig. 3a), very much more so than in *C. pervigilans* (Fig. 3c) or *C. pipiens* (Fig. 3d). A narrow ventral line of broad, flat, pale scales present on the subapical segment and the extreme base of the apical segment. A small subapical pale patch below on shaft. Tori dark brown with a few small dark scales. Vertex with numerous creamy, narrow, curved, decumbent scales and pale- to dark-brown upright forked scales. Proboscis mainly dark but pale below to a variable extent about the middle. Central area of mesonotum covered with narrow, curved, bronze-coloured scales, extreme edges with similar scales, intervening lateral areas with dark-brown scales which are separated into anterior and posterior patches by an intervening whitish spot halfway between the wing root and the scutal angle. This spot produced backwards to fuse with an indefinite area of whitish scales round the prescutellar bare space.

All scutellar scales whitish and very narrow. Some broader, creamy, curved scales on anterior border of mesonotum. Anterior and posterior pronota with narrow, curved, whitish scales. A few scales apparently present on the postspiracular area and the knob of the sternopleura but these areas rubbed. The usual upper and lower sternopleural and the mesepimeral scale patch well developed. A single well-developed lower mesepimeral bristle present in the usual position. Wings dark. Alula with a fringe of narrow scales. Squama with a strongly developed fringe of slender hairs. Anterior fork cell a little less than two and a half times the length of its stem. Haltere with stem pale and knob only slightly darkened. Legs mainly dark. Hind femur with a narrow, incomplete, dark dorsal line which does not reach base and which expands onto the anterior and posterior surfaces only at extreme tip. Hind tibia with a small pale spot at tip scarcely as long as broad. Fore tibial claw absent. First abdominal tergite wholly or largely dark, remainder with pale basal bands which are shallower on the more posterior segments
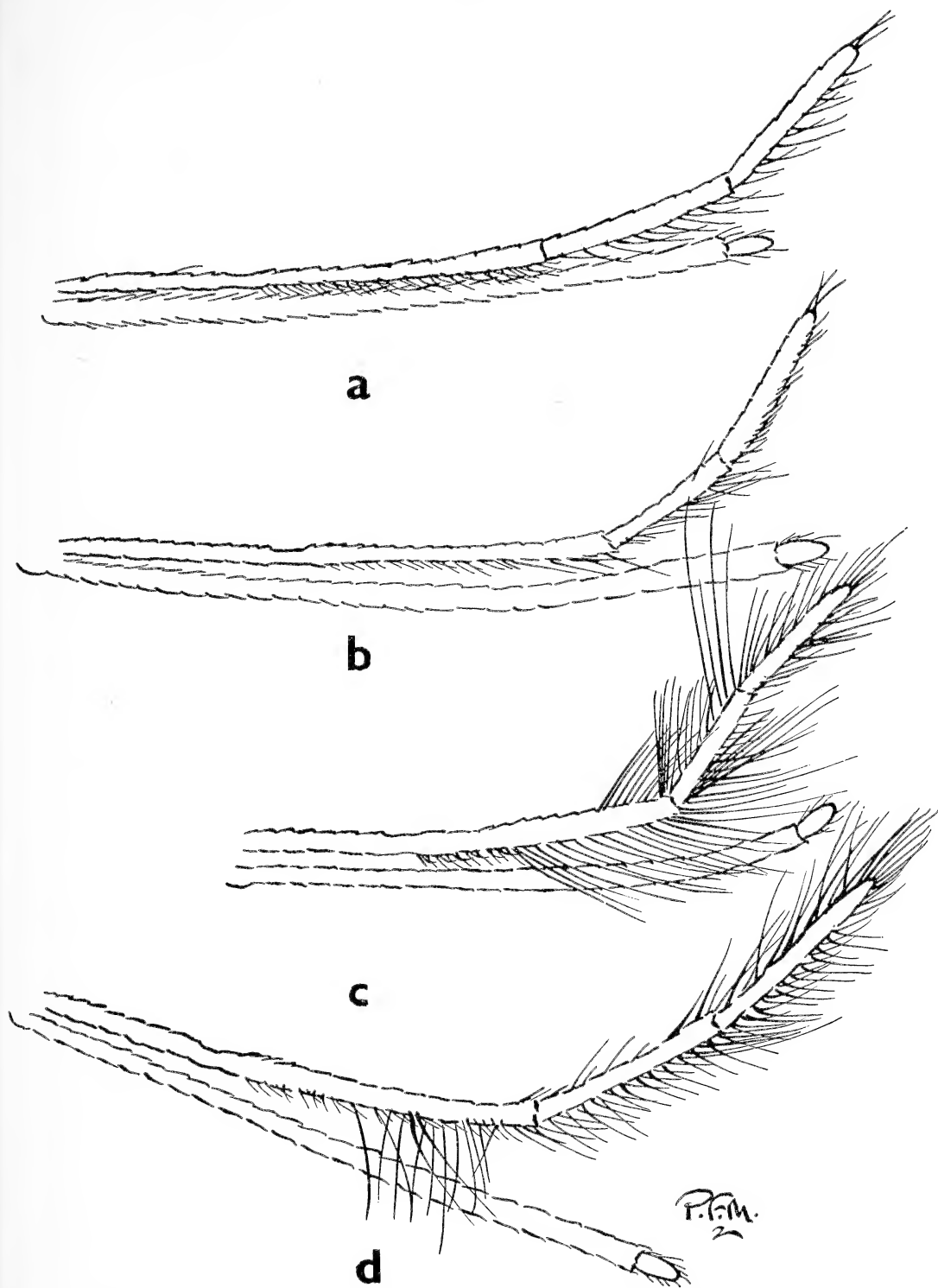
FIG. 3. Male palps. a, *C. iyengari* n. sp.; b, *C. pacificus;* c, *C. pervigilans;* d, *C. pipiens* ssp. *australicus* Dobrotworsky and Drummond.

where they are sometimes, but not always, prolonged backwards at the sides. Sternites with dark apical bands which tend to be prolonged forwards in the midline. These forward prolongations in some cases very broad and conspicuous, in others narrow and inconspicuous or absent.

Terminalia (Figs. 1a, 2a) with style broad, well formed but with a few oblique wrinkles about the middle, with small terminal appendage and two subapical setulae. Subapical lobe of coxite with narrow leaflet accompanied by a markedly flattened seta. Two sets of modified setae, as figured. Coxite not abnormally broad and with no more than the usual complement of long setae on the inner face. Phallosome with tip of inner division of dorsal arm modified as shown (Fig. 1a), outer division ("basal arm") strongly developed,

scooplike. Ventral arm much as in *C. pipiens*. Paraprocts with well-developed crown and basal arm. Xth tergites rather strongly sclerotized, each with 4 small setulae in the usual position. IXth tergite with setigerous lobes very broad and flat, each with about 10 setae.

ADULT FEMALE: Much as male but with palps only a little more than one-fifth the length of the proboscis. Pharynx and terminalia as figured (Fig. 4).

PUPA: Not seen.

LARVA: (Fig. 5). Head broader than long in about the proportion of four to three, in most cases darker than the remainder. Antenna about five-eighths the length of the head, more or less unicolorous except at extreme base, moderately strongly spiculate basad of the insertion of the antennal tuft but with only a few spicules distad of this point. Antennal
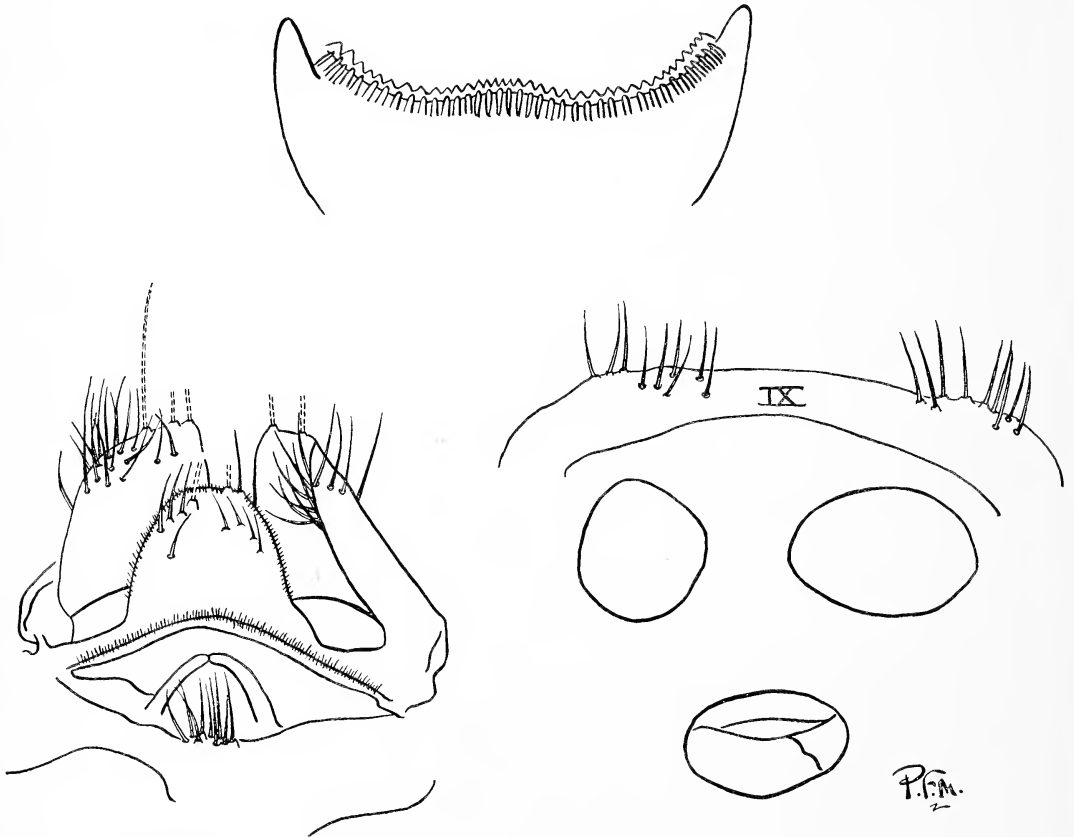
FIG. 4. *C. iyengari* n. sp. Female pharynx and terminalia. IX, ninth tergite.
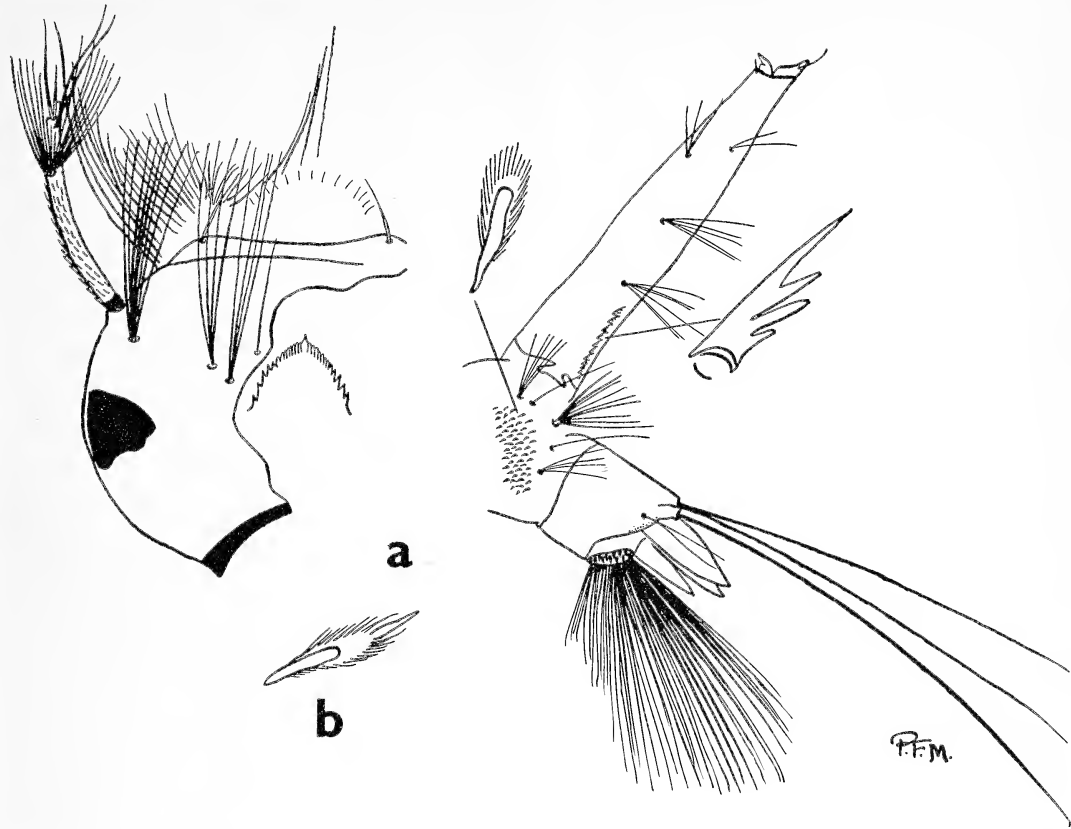
FIG. 5. a, *C. iyengari* n. sp., larva, head and terminal segments; b, comb spine of *C. pacificus*. Mentum somewhat enlarged.

tuft of about 20 rather short branches, inserted at about seven-tenths the distance from base to apex. Clypeal spines rather short, very slender, only slightly curved. Maxillary spine absent. Mentum with about 11–14 teeth on either side of the main central tooth. Head seta A about three-fifths the length of the head, B and C slightly longer, A with about 6–12 branches, B with 3–5, C with 4 or 5, *d* single. Comb of about 25–45 uniformly fringed scales. Siphon with distinct sinusoidal flexure. Index (uncrushed) about five to five and a half. Spine at base of dorsal valves small, straight, simple, recurved at extreme tip. Pecten of about 10–14 teeth, each with 2–5 coarse basal denticles (3 or 4 on the larger teeth). Subventral tufts varying in length from about four-fifths to one and one-fifth the diameter of the siphon at point of attachment. Distal edge of saddle with only very minute

spicules. Ventral brush with 12 tufts in the barred area. No precratal tufts. Saddle hair shorter than saddle, single or bifid. Upper caudal seta bifid or trifid, lower single.

BREEDING PLACES: Barrels, tanks, native canoes, cistern, hole in coconut trunk, rock hole in coral, and a deep well with foul and muddy water.[3] From all other known Pacific dark-legged *Culex* of the typical subgenus the present species is markedly distinct in male terminalia. It is readily distinguished from all except *C. pacificus* on the character of the male palps. (*C. atriceps* Edwards has these even more nearly bare and *C. marquesensis* Stone and Rosen (1953: 354) is intermediate between the present species and *C. pipiens*.) Separation of female adults and of larvae can be accomplished by means of the following keys.

[3] Some notes on the ecology of *C. iyengari* are included by one of us (J.R.). Assoc. Méd. Nouvelle-Calédonie, Bul. Numero Special, 1956.)

KEYS TO THE DARK-LEGGED *Culex* (*Culex*)
OF THE SOUTH PACIFIC
(EXCLUDING NEW GUINEA)

FEMALE ADULTS

1. Abdominal tergites with well-marked basal pale bands..........................2

   Abdominal tergites with basal lateral pale spots only.......... **C. atriceps** Edw.

2. Abdominal sternites with continuous dark apical bands..........................3

   Abdominal sternites with discontinuous median and apicolateral dark spots only (even these sometimes largely suppressed)..............................5

3. Anterior surface of hind femur wholly or largely dark..........................4

   Anterior surface of hind femur extensively pale.................**C. iyengari** n.sp.

4. Scutal integument pale with dark markings; scutal scales very small, more or less unicolorous. **C. marquesensis** St. and R.

   Scutal integument very dark; scutal scales coarse, forming a golden or light-brown pattern on a dark ground..............
   ....**C. pacificus** Edw.

5. New Zealand species only.............
   ....**C. pervigilans** Bergr.

   Australia, Tasmania, and New Caledonia ...**C. pipiens australicus** Dobr. and Dr.

   Widespread in Pacific area.............
   ....**C. pipiens fatigans** Wied.

C. pipiens australicus and *C. p. fatigans* are not constantly separable on external characters (Dobrotworsky and Drummond, 1953: 134) though the former is likely to be recognisably darker in general colouration in any particular locality. *C. pervigilans* also appears to be indistinguishable from these two (Edwards, 1924: 396). Its anterior fork cell varies from about 3.2 to 5.2 times the length of its stem. The colour of its mesonotal scaling is highly variable. The record of *C. p. australicus* from New Caledonia is the first from outside Australia and Tasmania. It is based on one male and three females bred from a batch of larvae collected by J.R. from rock pools in a stream bed near the bridge across the Ba River at Houailou on the east coast of New Caledonia on 9:vi: 1955. Further details are to be published elsewhere by Marks and Rageau.

FOURTH-STAGE LARVAE

1. Head setae B and C single.............
   ....**C. marquesensis** St. and R.

   These setae each with at least 3 branches.2

2. Siphonal index about 3.0 to 3.5; antenna about one-third of the length of the head; antennal tuft inserted only a little beyond halfway; upper caudal seta with at least 10 branches..........**C. atriceps** Edw.

   Siphonal index about 3.5 to 6.5; antenna at least half the length of the head; antennal tuft inserted at not less than two-thirds of the distance from base to apex; upper caudal seta with at most 3 branches
  3

3. Median denticle of comb teeth greatly hypertrophied, much stouter than the delicate lateral denticles..**C. pacificus** Edw.

   Comb teeth with more or less uniform fringe..............................4

4. Mentum with 6–9 teeth on either side of the main central tooth; siphonal index about 4.5 to 6.5 5

   Mentum with 10–14 teeth on either side of the central tooth; siphonal index about 3.5 to 5.5..........................6

5. New Zealand only. **C. pervigilans** Bergr.

   Australia, Tasmania, and New Caledonia ...**C. pipiens australicus** Dobr. and Dr.

6. Siphonal index about 3.5 to 5.0.........
   ....**C. pipiens fatigans** Wied.

Siphonal index about 5.0–5.5 . . . .
. . . .**C. iyengari** n. sp.

The highly characteristic comb spines of *C. pacificus* (Fig. 5b) appear to have been overlooked by previous authors (Buxton and Hopkins, 1927: 87; Lee, 1944: 108). The description of the larva of *C. p. fatigans* by Woodhill and Pasfield (1941: 212) seems to have been based on mixed material (Dobrotworsky and Drummond, 1953: 132).

For descriptions of the adult of *C. atriceps* the reader is referred to Edwards (1926: 105; 1928: 279), and for *C. pacificus* to Edwards (1916: 360). Iyengar (1955) gives a general account of the distribution of mosquitoes in the area under consideration.

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Hawaiian Helminths 1. *Trigonocryptus conus* n. gen., n. sp. (Trematoda: Fellodistomidae)[1]

W. E. MARTIN[2]

THIS WORK was done at the Hawaii Marine Laboratory, University of Hawaii. Twenty-nine balloon fish, *Tetraodon hispidus* L., collected by trap, were examined for helminths. Four harbored in their intestine a total of eight trematodes which do not fit into any genus or species thus far described.

The worms were killed in cold Heidenhain fixative under light cover glass pressure, stained in celestine blue B, and mounted in H.S.R. Microscopic Mounting Medium.

All measurements are expressed in millimeters.

TRIGONOCRYPTUS n. gen.

GENERIC DIAGNOSIS: Fellodistomidae: Small conical trematodes with ventrolateral body folds separated posteriorly and converging anteriorly. Posterior end of body bears a short velum laterally and dorsally. Inverted tail cone present. Cuticula relatively thick, spined. Oral sucker subterminal with ventrolateral extensions. Ventral sucker large, transversely elongate and ridged, indented anteriorly and pos-

teriorly. Prepharynx and esophagus very short. Pharynx oval to spherical. Ceca short, saccular, not extending posterior to mid-body. Testes paired, opposed, oval, near posterior end of body. Cirrus sac oval to nearly spherical, immediately anterior to or slightly overlapped by acetabulum, encloses a weakly bipartite seminal vesicle, a well-developed prostate and a short cirrus. Ovary oval, median, partly between to a short distance anterior to testes. Seminal receptacle near, usually smaller than, ovary. Mehlis gland beside ovary, inconspicuous. Vitelline follicles in two major groups on each side of body extending from anterior acetabular to posterior oral sucker levels. Uterus mainly confined to posterior half of body, between and anterior to testes. Uterus and cirrus use common genital atrium which opens to outside medially and ventral to gut bifurcation. Eggs oval, numerous, operculated, with tiny knob at anopercular end. Excretory bladder U-shaped. Parasitic in the intestines of marine fish.

GENOTYPE: *Trigonocryptus conus.*

Trigonocryptus conus n. sp.

Figs. 1–5

SPECIFIC DIAGNOSIS: With characters of genus. Body conical and pink in life, triangular when fixed under pressure. Cuticle 0.012–0.016 thick, armed with spines. Spines approximately 0.017 long with shouldered peripheral terminations (Fig. 4). Body 1.37–1.82, average 1.58 long and 0.98–1.4, average 1.24 wide. Oral sucker subterminal, muscular, with folds meeting those of the body wall, 0.39–0.55,

1.

2.

3.

4.

5.

average 0.44 anteroposteriorly and 0.41–0.55, average 0.48 transversely. Ventral sucker large, muscular, indented anteriorly and posteriorly, with two or three transverse ridges, 0.45–0.59, average 0.52 anteroposteriorly and 0.64–1.02, average 0.86 transversely. Prepharynx short, pharynx 0.093–0.112, average 0.10 anteroposteriorly and 0.081–0.121, average 0.11 transversely. Esophagus short, ceca thin walled, short, saccular, not extending beyond body equator. Testes near posterior end of body, opposed, oval, 0.17–0.28, average 0.22 long and 0.14–0.21, average 0.17 wide. Vasa efferentia join just before reaching cirrus sac. Cirrus sac median, immediately anterior to or partially overlapped by acetabulum, containing weakly bipartite seminal vesicle filled with sperm, a well-developed prostate, and a short cirrus which may project into the genital atrium. Genital pore median and ventral at level of gut bifurcation. Ovary median, usually a short distance anterior to testes, 0.096–0.17, average 0.15 long and 0.084–0.15, average 0.12 wide. Seminal receptacle pyriform, usually a short distance posterior and to the right of the ovary. Mehlis gland close to ovary, inconspicuous. Vitelline follicles in two major clusters on each side of body between anterior acetabular and oral sucker levels. Common vitelline duct not expanded to form reservoir. Uterus after leaving ovary passes posteriad to loop between the testes then extends anteriad to loop transversely and fill much of the acetabular region of the body. It then passes anteriorly to the genital atrium. The uterus of mature worms is filled with eggs. Newly formed eggs colorless, older eggs brown. Eggs 0.037–0.046, average 0.041 long and 0.022–0.025, average 0.023 wide, operculated, with a small knob at anopercular end. Excretory vesicle U-shaped, thin walled, with pore opening medially and subterminally.

DISCUSSION

The genus *Trigonocryptus* most closely resembles *Paradiscogaster* Yamaguti, 1934. The major difference is in the vitellarian distribution, in one cluster on each side of the body confined to the cecal region in *Paradiscogaster*, and in two clusters on each side of the body extending from the acetabulum to the oral sucker in *Trigonocryptus*. Other differences are the ventrolateral extensions of the oral sucker in *Trigonocryptus* while this organ in *Paradiscogaster* has the usual circular outline; the unusual body shape in *Trigonocryptus* with a ventral, triangular depression, a velum on the lateral and dorsal margins of the posterior part of the body, and a truncated posterior end while the body shape is pyriform in *Paradiscogaster*. Yamaguti (1938) described a small tail cone in *Paradiscogaster chaetodontis*. *Trigonocryptus conus* has an inverted tail cone, dorsal to the excretory pore, which was never seen everted even in active worms. *Paradiscogaster piriformis* Yamaguti, 1934, was found in *Pleuronichthys cornatus* in Japan (Yamaguti, 1951); *P. chaetodontis* Yamaguti, 1938, in *Chaetodon collaris* in Japan and *C. strigangutus* and *C. trifasciatus* in Okinawa (Yamaguti, 1953); and *P. caranxi* (Srivastava, 1939) Yamaguti, 1953, in *Caranx kalla* in India. Although a goodly number of Hawaiian chaetodons and a few carangids have been examined, no species of *Paradiscogaster* or *Trigonocryptus* have been found in them. Hanson (1955) has reported a related form, *Discogasteroides ha-*

FIGS. 1–5. *Trigonocryptus conus:* 1, Dorsal view; 2, ventral view; 3, egg; 4, body spine; 5, terminal genitalia. A, Acetabulum; C, cecum; Ci, cirrus; CS, cirrus sac; EV, excretory vesicle; G, genital pore; O, ovary; OS, oral sucker; P, pharynx; PR, prostate; S, seminal receptacle; SV, seminal vesicle; T, testis; U, uterus; V, vitellaria; V, velum. All drawings made with the aid of a camera lucida.

waiensis, from a Hawaiian trunk fish, *Ostracion sebae* Bleeker.

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Calcareous Concretions and Sheets in Soils
Near South Point, Hawaii[1]

G. DONALD SHERMAN and HARUYOSHI IKAWA[2]

WHITE CALCAREOUS concretions and sheets are found in the soils of the Pakini series of the Reddish Brown great soil group in the South Point area of the Kau section on the island of Hawaii. These soils have developed on a series of wind-deposited volcanic ash as described by Palmer (1931) and Wentworth (1938). The calcareous concretions found in these soils have been formed by biogenetic processes in that the carbonates have been precipitated around the roots of plants, especially the deep-rooted plants. These rhizo-concretions occur only in the subsoil, B horizon, of the soil profile. The calcareous sheets occur as layers in the parent material of this soil which is the aeolian silt and sand. The character of the effervescence of these calcareous depositions indicates the presence of appreciable quantities of dolomite in the carbonate fraction of these materials. Wentworth (1938) has reported the occurrence of both calcareous stem casts and calcareous sheets in overlying, looser aeolian ash of this area. The occurrence of calcareous rhizo-concretions has been mentioned by Bryan (1952) in his report on soil nodules. The occurrence of dolomite in soil concretions has not been described; however, the occurrence of dolomitization in soils has been described by Sherman et al. (1947).

This study was initiated to determine the nature of the composition of these calcareous rhizo-concretions and sheets. In order to do

this, samples of these materials were collected and analyzed by methods designed to determine the composition of carbonates in soils as described by Sherman (1937).

The samples were collected from an area of soils which had been classified by Cline et al. (1955) as the Pakini very fine sandy loam—a soil which has developed from the moderate weathering of a series of layers of volcanic ash. The surface horizon of about 5 to 6 inches is dark-brown very fine sandy loam (A_{11}) over a slightly lighter colored very fine sandy loam (A_{12}) of varying thickness. The total thickness of the combined A_1 horizon does not exceed 15 inches. The material below the A horizon is a B horizon of yellowish-red silty material containing sand and gravel. In places a weak blocky structure has developed in contrast to the crumb structure of the A horizon. This material gradually grades into a reddish-yellow silt loam in which continuous white layers (sheets) of carbonates occur as bands about half an inch in thickness. The carbonate-coated decayed roots of plants of the previous original vegetation of the area occurred in this layer and in the B horizon immediately above it and at a depth of 36 to 58 inches below the surface. The original vegetation has been removed and replaced by grasses suitable for grazing.

The rhizo-concretions of carbonates are shown in Figure 1. They retain the general shape of the root. The concretions in the center row of the illustration show a deposition layer on the outer surface of the root and a mixture of carbonates and decomposed organic material in place of the root in the center of the concretion (inner portion). The outer

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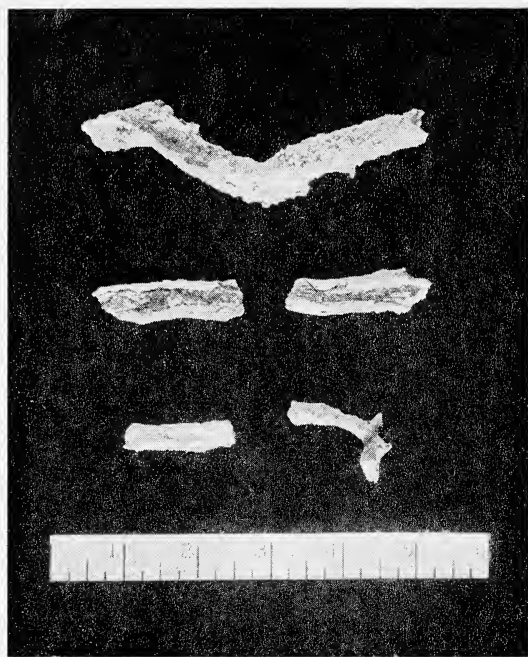
255

FIG. 1. Calcareous rhizo-concretions found in soils near South Point, Hawaii. Size of concretions can be compared with the scale shown in inches.

layer apparently was deposited around the living root and the inner portion was deposited after decomposition of the root at a later time. The outer layer was comparable in appearance to the calcareous layers or sheets in the soil. The deposition of the carbonate appeared to occur on the surface of very fine texture layers occurring in the wind-blown materials, usually clay layers. Samples were collected to represent the outer and inner portions of rhizo-concretions and the sheets.

The data obtained from the chemical analysis to determine the composition of the carbonates are presented in Table 1. The total carbonate content of the inner portion of the rhizo-concretions was found to be a little less than 82 per cent, the highest carbonate concentration of the calcareous concretions. The total carbonate contents of the outer portion of the rhizo-concretion and of the calcareous sheets were almost identical, ranging from 65 to 67 per cent. This would suggest that the outer portion of the rhizo-concretions and the

calcareous concretions were formed by similar processes of precipitation. These latter calcareous depositions are dense and hard while the carbonate material inside the tubular rhizo-concretions is soft and powdery; thus, the latter depositions constitute only a small portion of the total carbonates. The powdery carbonate of the inner tubular structure could have been precipitated from the waters carrying bicarbonates of calcium and magnesium. The precipitation by the action of alkaline earth elements on ammonium carbonate developed by the decomposing organic matter as suggested by Mathias (1931) should not be discounted. The outer portion of the rhizo-concretion and the sheets were probably precipitated by the precipitation of particles of carbonate near the root or in the more alkaline soil layer and the precipitation of bicarbonates continues due to increasing alkalinity, a process proposed by Gillam (1937). Similar rhizo-concretion formation of pyrolusite has been described by Sherman et al. (1949).

The data in Table 1 show an appreciable quantity of magnesium carbonate in these concretions. The highest content was found in the inner portion of the rhizo-concretions which was found to contain 23 per cent magnesium carbonate, in other words, a little over 62 per cent of the carbonates was in the form of dolomite. The outer portion of these concretions contained 17.0 and 16.5 per cent magnesium carbonate, or in other words, 56 per cent of the carbonates were in the form of dolomite. The calcareous sheets contained 18 per cent magnesium carbonate, equivalent to 58 per cent of the carbonates in the form of dolomite. Thus, active dolomitization is occurring in the formation of these concretions. The determination of exchangeable cations in these soils has revealed a high content of exchangeable magnesium. The high magnesium saturation in the exchange complex is the result of a high content of magnesium ions in the waters which circulate through the weathing system. This would also give an ample supply of magnesium to form the magnesium

TABLE 1

THE CHEMICAL COMPOSITION OF THE CARBONATES IN RHIZO-CONCRETIONS AND CALCAREOUS LAYERS OCCURRING IN THE SOILS OF THE PAKINI SERIES, SOUTH POINT, KAU, ISLAND OF HAWAII

SAMPLE	TOTAL CARBONATES	MINERALS OTHER THAN CARBONATES	$CaCO_3$ IN SAMPLE	$MgCO_3$ IN SAMPLE	CARBONATES AS DOLOMITE	$K = \dfrac{CaCO_3}{MgCO_3}$
	Per cent	Per cent	Per cent	Per cent	Per cent	
Rhizo-concretion #1 inner portion..........	81.6	14.2	58.5	23.1	62.1	1.61
Rhizo-concretion #1 outer portion..........	66.1	25.3	49.1	17.0	56.5	1.77
Rhizo-concretion #2 inner portion..........	81.7	14.4	58.4	23.3	62.5	1.60
Rhizo-concretion #2 outer portion..........	65.4	25.2	48.9	16.5	55.2	1.81
Calcareous sheet #1.......	67.3	28.6	49.3	18.0	58.4	1.71
Calcareous sheet #2.......	67.3	28.5	49.4	17.9	58.2	1.72

bicarbonate which would be essential to the process of dolomitization. Since calcium ions occur in a greater concentration, the precipitated carbonates would show an excess of calcium carbonate. Thus, the rhizo-concretions and sheets should be considered to be dolomitic lime depositions.

SUMMARY

The results of this study have resulted in the following conclusions. The highest total carbonate and carbonates in the form of dolomite occur in the inner portion of the calcareous rhizo-concretions. The similarity between the composition of the outer portion of the rhizo-concretions and the calcareous sheets indicates that these concretionary depositions occurred under the same conditions and are undoubtedly deposited by the same process. The proportion of magnesium carbonate in all of these concretions indicates that active dolomitization is occurring and that dolomite is being deposited in the concretion. These concretions should be considered as dolomitic lime concretions.

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Barriers to Protect Hilo from Lava Flows[1]

Gordon A. Macdonald[2]

The city of Hilo, on the island of Hawaii, lies on the flank of one of the world's most active volcanoes, Mauna Loa. For more than a century the danger of destruction of the city by lava flows has been recognized. Old documents recount the apprehension with which Hilo residents watched the advance of the lava flows of 1852 and 1855. In 1881 concern was even greater, as the flow front crawled within a mile of the shore of Hilo Bay. Early in his studies of Hawaiian volcanoes, the late Dr. Thomas A. Jaggar recognized the threat to Hilo, and for many years the safety of the city and methods by which it might be insured were among his principal concerns (Jaggar, 1931, 1949).

In 1937, following preliminary studies by the staff of the Hawaiian Volcano Observatory, Jaggar proposed the building of a barrier, or barriers, on the lower slopes of Mauna Loa to deflect lava flows from Hilo harbor and its immediate vicinity. Such a barrier would consist essentially of a great wall stretching diagonally across the slope. The purpose of the barrier would not be to hold back the flow, like a dam, but to turn the flow and direct it away from the vital area. In 1938 a study of the project was begun by the U. S. Engineer Department (now U. S. Army, Corps of Engineers). A route and design for the barrier were chosen, and the entire proposal was subjected to careful study. It was found in the estimate of the Engineer Department to be entirely feasible. The official report, in January 1940, stated: "The District Engineer believes it is possible to protect the harbor and city by a properly located and constructed barrier." The construction of the barrier was not carried

out because it was considered not to be a justified function of the War Department (Jaggar, 1945: 340–341).

It is the purpose of this paper to review the need of protection for Hilo, and the methods by which it might be accomplished. When I first heard of the proposal to protect Hilo from lava by means of walls to deflect the flows, I was very doubtful whether the method could be successful. However, the study of active flows during 7 eruptions and of many older flows, in the course of 17 years of experience with Hawaiian volcanoes, has convinced me that such walls have an excellent probability of succeeding. Attempts to build diversion barriers during the 1955 eruption of Kilauea have not weakened that conviction, though they have shown that the walls must be carefully planned, and properly placed and constructed.

Whether barriers are likely to be needed, and whether successful barriers can be built, are questions properly falling within the field of the volcanologist. Answers to only those questions are attempted herein. The question of whether a barrier should be built involves complex considerations of relative values of the area to be protected, income to be expected from the area, effects of loss of the area upon the economy of surrounding areas, effects of displacement of population as a result of loss of the area and influence on adjacent areas, cost of construction of the barrier plus interest on the cost, the ability of the community (either locally or at large) to pay this cost, and no doubt other factors. There are also the legal questions arising from diversion of lava onto land that otherwise might not have been covered during that eruption. These questions fall outside the province of the volcanologist and must be decided by economists, sociologists, and lawyers.

NEED FOR PROTECTION

Hilo Bay lies at the junction of the slope of Mauna Loa volcano with that of Mauna Kea to the north (Fig. 1). Most of the city of Hilo, south of the Wailuku River, is built on geologically recent lava flows from Mauna Loa. The very existence of Hilo Bay is the result of these flows, which constitute all of the broad promontory that extends eastward to Leleiwi Point. These flows cannot now be dated in years, but probably most of them are less than 2,000 years old.

Since about 1820, when our real knowledge of Hawaiian volcanoes begins, Mauna Loa has been among the most active volcanoes in the world. During that period it has erupted on an average once every 3.6 years, and the total lava poured out has been more than 4 billion cubic yards. Nothing in the geological record indicates that this degree of activity is abnormal in the history of the volcano, nor is there reason to expect that the degree of activity in coming centuries will differ appreciably from that of the last.

The vents of flank eruptions of Mauna Loa are concentrated along two zones of fracturing, known as rift zones, that extend respectively east-northeastward and southwestward from the summit of the mountain. The northeast rift zone averages about a mile in width, and trends almost directly toward Hilo. It is marked at the surface by innumerable fissures in the ground, and lines of cinder and spatter cones built at the sites of eruptions. The three small cinder cones known as the Halai Hills, within the city of Hilo itself, appear to lie on the prolongation of the northeast rift zone; but fortunately the portion of the rift zone below an altitude of 6,000 feet has been inactive for many hundreds of years. Eruption along the northeast rift zone has built a broad, rounded ridge trending toward Hilo. The north slope of this ridge intersects the south slope of Mauna Kea, producing a broad valley through which the Wailuku River and its tributaries flow eastward into Hilo Bay (Fig. 1). Because of this topographic configuration, all lava flows erupted from the northern part of the rift zone below approximately 11,500 feet altitude are directed toward Hilo within a belt about 6 miles wide. Whether or not they reach Hilo depends largely on the volume of lava released during the eruption, and whether it is concentrated into a single flow or spread as several flows over the upper slope of the mountain.

It is the restriction of flows approaching Hilo to this relatively narrow (6 miles wide) belt just south of the Wailuku River that makes feasible the protection of the city by diversion barriers.

Flows issuing at points on the northeast rift zone above 12,000 feet altitude probably will turn westward in the Humuula Saddle (as did the flow of 1843), and consequently do not constitute a threat to Hilo.

Since 1850 there have been 6 major eruptions in the northeast rift zone, producing 8 major lava flows with an aggregate volume of
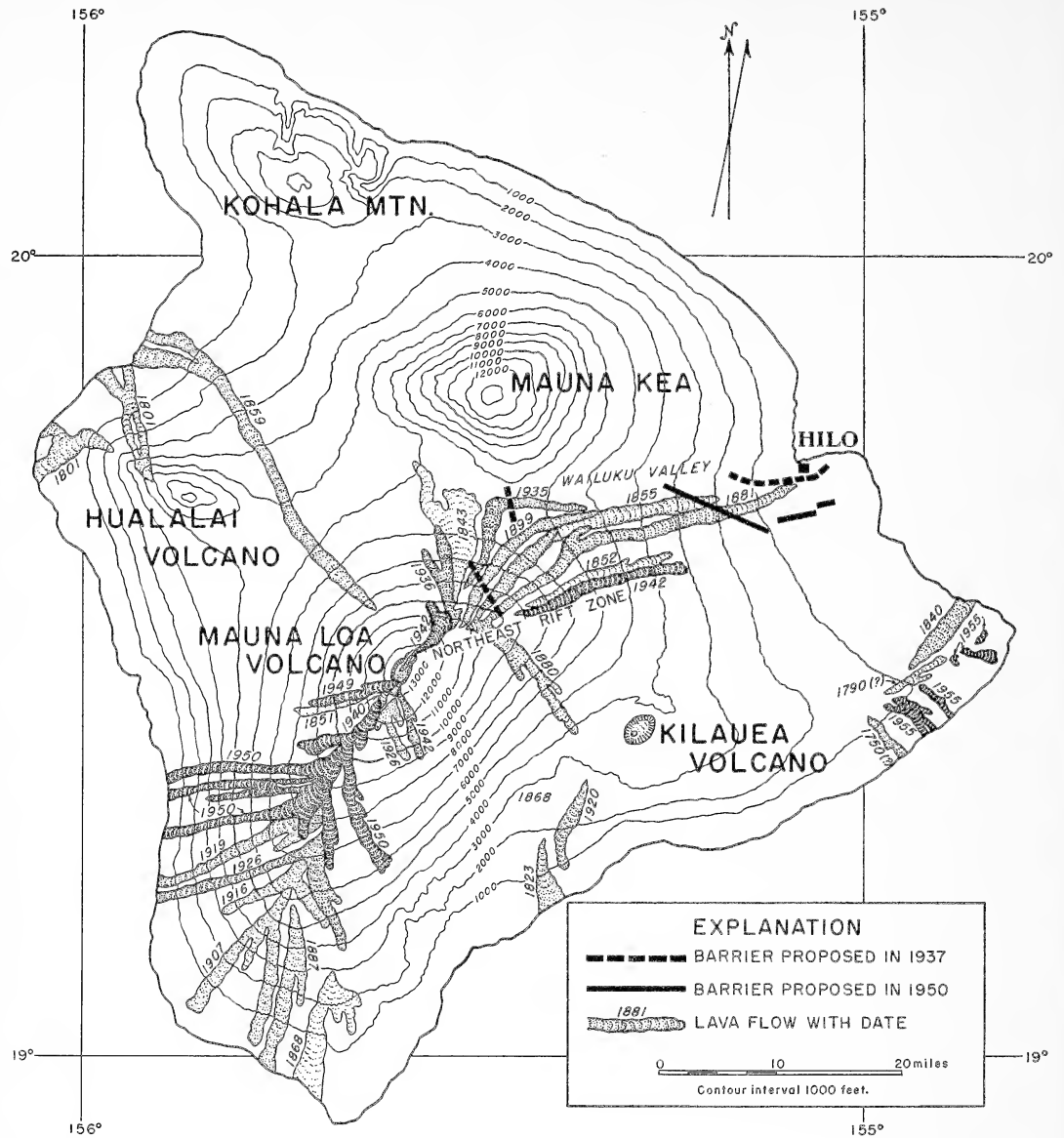
FIG. 1. Map of the island of Hawaii, showing the location of the city of Hilo, and of barriers proposed to protect it from lava flows originating on the northeast rift zone of Mauna Loa.

more than 1,000,000,000 cubic yards. Of these, 7 flows have advanced toward Hilo, and in 1881 lava actually invaded part of the present city. The volume of the 1881 flow toward Hilo was approximately 250,000,000 cubic yards. In 1942, a flow with a volume of approximately 100,000,000 cubic yards started from a vent at 9,200 feet altitude and advanced northeastward 16 miles, coming to a halt 12 miles from the shore of Hilo Bay. As compared with these flows from the northeast rift zone, the 1859 flow on the northwest slope of the mountain and the 1950 flows from the southwest rift zone each had a vol-

ume of approximately 600,000,000 cubic yards. This latter volume is more than twice that of the 1881 flow, and 6 times that of the flow of 1942. The distance from the source of the 1859 flow to the point where it entered the ocean is 32 miles. The vents of the 1942 and 1881 flows are 28 and 30 miles, respectively, from the shore at Hilo. If either the 1881 or the 1942 flows had had a volume equal to that of the 1859 or 1950 flows, the lava almost certainly would have entered Hilo Bay, and doubtless would have overrun much of the city.

In the vicinity of Hilo, lava flows of geologically recent age rest on a bed of yellow ash (Stearns and Macdonald, 1946: 63–78), and early flows of this group buried charcoal that has been shown by radio-carbon dating to have been formed about 2,000 years ago (Macdonald and Eaton, in preparation). It is estimated that during the interval since then about 20 or 25 lava flows have entered the Hilo area. Thus, based on these crude statistics as well as on the historic record, an average of about one flow per century can be expected to enter the city of Hilo. Probably about one of every three such flows will enter the bay. The last flow to enter the present city was that of 1881, and no flow has entered the bay since sometime previous to 1800. Obviously, these figures are inadequate for the determination of the mathematical probability of the entrance of lava into the city or harbor within any given length of time; but within their limits they suggest that a flow may be expected to enter the city within the next 25 years, and to enter the harbor within the next century. No one can predict when this may happen—whether within the next 5 years or a century or two hence—but the threat is apparent and the implications to the economy of the island demand consideration of protective or palliative measures.

The volume of water in Hilo harbor, and especially that in the deep ship channel, is comparatively small. The total volume east of a line connecting the end of the breakwater with the mouth of the Wailuku River is approximately 45,000,000 cubic yards, and in the same area the central channel below a depth of 5 fathoms has a volume of only about 3,000,000 cubic yards. Part of any flow entering the harbor would project above sea level, of course, and part would occupy the shallow margin of the bay, but the topography of the bay floor would guide the advancing flow directly into the most important part of the harbor—the ship channel. Once in this submerged valley the lava would tend to spread along it. Both the natural valley wall north of the channel, and the breakwater, would serve as barriers to confine the flow to the harbor. Thus 100,000,000 cubic yards of lava entering the harbor almost certainly would make it unusable, and half that volume probably would have the same result. Indeed, a very much smaller volume entering the ship channel, as it very probably would do, would cause serious damage.

The loss of Hilo harbor would be disastrous to the present economy of much of the island of Hawaii, for there is no other harbor in that part of the island capable of handling the cargo that moves through the port of Hilo. Furthermore, the loss might well be permanent. The congealed lava in the bay could not to any large extent be removed by simple dredging, and a difficult and very costly blasting operation would be necessary to clear the harbor.

It should be noted that in time of eruption the supply of fresh water for Hilo may present a serious problem. Most of the city's water now comes from the Wailuku River. A lava flow entering the Wailuku drainage basin might greatly reduce the volume of available water and render the remainder unusable without special treatment. During the 1855 eruption the river water became much discolored by organic matter from burned vegetation, but at that time it caused no trouble because the city's water was obtained from springs. The possibility of lava flows seriously damaging Hilo's water supply was pointed out sev-

eral years ago (Stearns and Macdonald, 1946: 258) and the construction of wells to provide an alternative or supplementary water supply was suggested. Such wells should be kept within the line of the proposed lava diversion barrier, protected as far as possible from lava flows.

INADEQUACY OF AERIAL BOMBING

The use of explosives to alter the course of lava flows was first suggested by the late Lorrin A. Thurston in the early 1920's, and was elaborated and made specific by Jaggar (1931, 1936). The idea of emplacing the explosive by means of aerial bombs was suggested by the late Guido Giacometti at the time of the 1935 eruption.

There are three general ways in which bombing can divert lava flows: (1) by breaching a lava tube in a pahoehoe flow, (2) by breaching an open channel in an aa flow, or (3) by breaking down the walls of the cone at the vent (Finch and Macdonald, 1949; 1951: 128–132). (For a discussion of the characteristics of aa and pahoehoe flows, see Macdonald, 1953.)

(1) At first the main feeding streams of all flows are in open channels, but after the first few hours or days of activity the main stream of a pahoehoe flow crusts over and develops a roof. Thereafter it flows through a tube, from a few feet to as much as 50 feet in diameter, resembling a great pipe or subway. Bombs dropped on this tube may break it open, clogging the tube partly with debris from the shattered roof and partly with viscous aa lava resulting from the violent agitation of the fluid lava in the tube. The clogging may cause an overflow from the tube at that point and a consequent diversion of the main feeding stream of the flow. If the diversion is several miles upstream from the former advancing flow front, several days may pass before the front of the new flow reaches as great a distance from the vent as had the earlier flow front.

(2) The main feeding river of an aa flow remains largely open, but repeated overflows gradually build up natural levees on each side

of the stream, and after the first few days the stream commonly is flowing at a level several feet higher than the adjacent land surface. Breaking down the levee by bombing permits the liquid to escape from the old channel and start a new flow. The removal of part or all of the supply of liquid lava from the old channel causes the advance of the old front to slow greatly or stop altogether, and it may be several days before the new front reaches a point as far from the vent as that reached by the old one. At that time bombing can be repeated if necessary.

(3) Commonly the pool of liquid lava in the cone, which feeds the flow, is at a level several feet above the ground surface adjacent to the cone. As with the aa levees, breaking down of the walls of the cone allows the lava to spill out laterally, starting a new flow and depleting the supply of lava feeding the previous flow.

The last method, suggested independently by Finch (1942) and the writer (Macdonald, 1943), has not yet been tried, although the natural breakdown of the cone walls during the 1942 eruption produced essentially the same effect that would be brought about by bombing. The first method was employed under the direction of Jaggar in 1935, and the second under the direction of Finch in 1942. In neither case did the bombing wholly divert the flow, but in both it was demonstrated that the methods can be successful under favorable circumstances. However, bombing methods can be used only where topography is favorable and at times when the lava flow has formed well-developed tubes or channels between elevated levees, or when a large cone of appropriate shape has been built at the vent. Furthermore, the bombs must be very accurately placed to produce the desired effects, and this in turn requires good visibility of the targets from the air. During times of eruption visibility is often very poor over the flows in any area because of the clouds of volcanic fume and smoke from burning forests. In the area southwest of Hilo visibility is apt to be

especially poor because of the combination of these with the normal trade-wind clouds generally present even in times of noneruption. For days or even weeks at a time targets in that area may not be visible from the air. This is emphasized by experience during the 1942 eruption, when the most favorable targets chosen during a reconnaissance flight could not be seen on succeeding bombing flights, and the bombs had to be dropped on less favorable targets.

Possibly the bombs could be placed accurately, even in dense clouds and smoke, by the use of infrared or radar bomb sights. Also it has been suggested that heavy artillery fire, directed by ground observers close to the targets, might be used instead of bombing in order to overcome the difficulties of poor visibility from the air. The method should be tried. It appears doubtful, however, whether the explosive charges delivered in that manner could be sufficiently large to produce the desired results.

Still another limitation to the use of bombing arises from the considerable length of time required to load planes with bombs and fly them to the scene of eruption, and to select targets. Rapidly moving flows may already have done their damage by the time the bombers arrive. Thus, for instance, the lava flow that destroyed part of Pahoehoe village on the night of June 1, 1950, could not have been diverted by bombing because of the very short time (about 3 hours) in which it reached the village, and because its channel walls were not sufficiently well established to permit them to be broken down by bombs. The same would be true of a similar rapid flow toward Hilo. Fortunately, a flow of equal rapidity is unlikely in the area near Hilo, because of the much gentler slopes on the Hilo side of the mountain and the much greater distance of Hilo from any likely vents. Nevertheless, flows too rapid to be bombed successfully before they reach Hilo are possible. The lava flow of 1859 traveled the entire distance of 32 miles from the vents to the ocean in less

than 8 days, over slopes averaging about the same as those southwest of Hilo.

Thus bombing cannot be relied upon to protect Hilo from lava flows. It is a useful auxiliary method, and should be employed when possible even if lava barriers have been built, to help preserve the barriers in a condition of maximum usefulness for future eruptions.

EFFECTS OF LAVA FLOWS ON WALLS

The idea of constructing walls to control the course of lava flows is not new. In 1881, a loose stone wall was hastily constructed across what was then the course of Alenaio Stream, in an attempt to prevent the lava from reaching the Waiakea mill (on the southern outskirts of Hilo). The pahoehoe lava reached the wall, formed a pool behind it, and eventually spilled over the wall without displacing it. This is an interesting illustration of the ability of even a loose stone wall to withstand the thrust of a lava flow. By chance, the flow stopped when the lava had progressed only a few feet beyond the wall. If the flow had not stopped, the attempt to confine the lava was doomed to certain failure because the wall was built as a dam directly across the course of the flow, and even though the wall confined the liquid lava for a short time the reservoir was too small to hold any great volume of lava.

Also in 1881, a much greater project in the Hilo area was planned, but never executed. W. R. Lawrence, an engineer for the Hawaiian government, recommended the construction of an embankment along the northern side of Alenaio Gulch to confine the lava to the gulch and prevent it from spreading northward into the main part of Hilo. Arrangements were being made to put 1,000 men to work on the project, when the flow ended and the construction became unnecessary (Baldwin, 1953: 3). If the project had been carried out, it probably would have been successful.

For many years farmers on the slopes of Vesuvius have built small walls in an effort to keep mud flows from entering their vine-

yards, but the method does not appear to have been employed against lava flows (F. M. Bullard, personal communication, 1956). Except for the barriers built in 1955, described on a later page, I know of only one other deliberate attempt to control a lava flow by means of a wall. In 1951, lava flows from Mihara volcano, Japan, accumulated in the Oshima caldera and approached the level of a low gap in the caldera wall directly above the village of Nomashi. In an effort to prevent the lava from spilling through the gap and threatening the village, the villagers constructed across the gap a masonry wall (Fig. 2) 15 meters long, 2 to 4 meters high, and 3 meters thick (Mason and Foster, 1953: 257). The wall was intended to impound the lava like a dam, until the lava reached a level at which it would spill through another nearby gap where it would not threaten the village. The eruption

stopped before the lava reached the wall, but there is every likelihood that the wall would have accomplished its purpose.

Several examples of lava flows coming in accidental contact with stone walls have been observed. In 1906, an aa lava flow invaded the town of Boscotrecase, on the south slope of Vesuvius, and entered the churchyard which was enclosed by a masonry wall about 10 feet high. The lava filled the churchyard nearly to the level of the top of the wall, but did not damage the wall (Jaggar, 1945: pl. 1). Nearby, lava moving along the village streets did not seriously disturb the walls of the adjacent buildings (Fig. 3). Most of the damage to the masonry, visible in Figure 3, was caused by fire in the buildings. (At other places buildings were seriously damaged, especially where the walls lay at right angles to the direction of advance of the flow.)
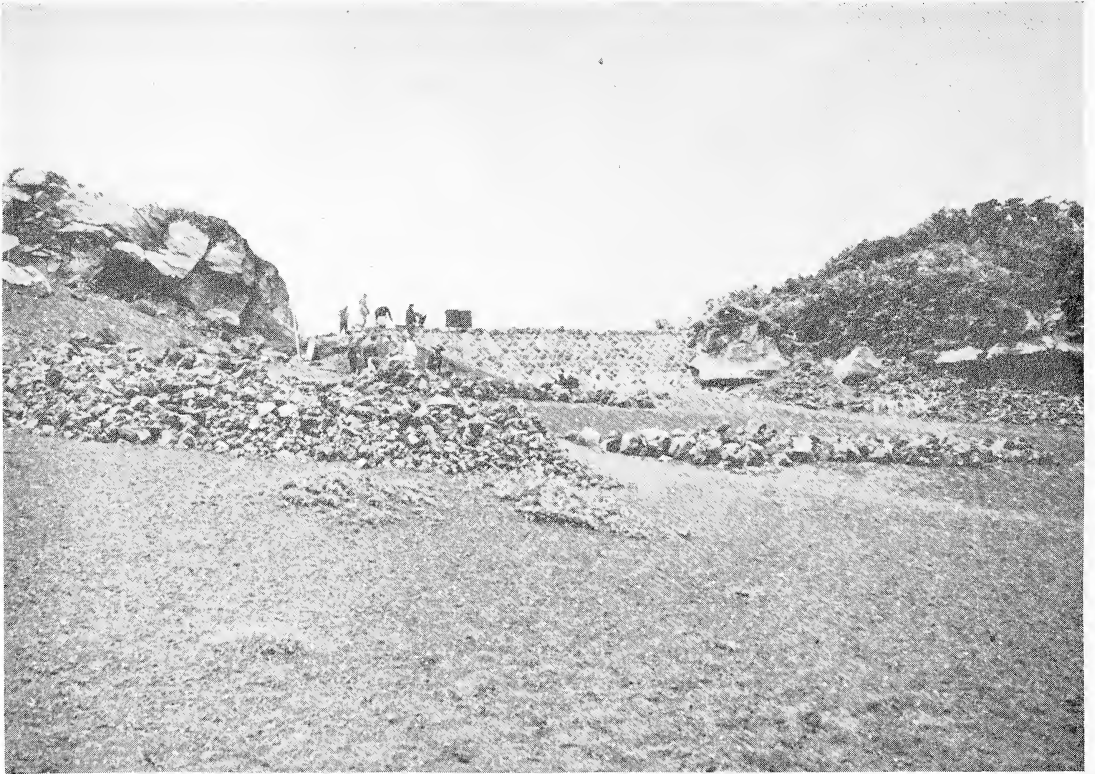
FIG. 2. Masonry wall built across a gap in the wall of Oshima caldera, Japan, in 1951, to prevent lava from spilling through the gap and endangering the village of Nomashi. Photo by Helen L. Foster, U. S. Geological Survey.

FIG. 3. Lava flow filling a street in the village of Boscotrecase on the slope of Vesuvius during the eruption of 1906. Note that the masonry walls are little disturbed. Photo by T. A. Jaggar.

In 1920, a flow of pahoehoe transitional to aa, from the southwest rift of Kilauea, encountered a loose stone wall 2.5 to 3 feet high and 18 inches thick lying at an angle of about 60° to the course of the flow, piled up behind it, and eventually spilled over it without damaging the wall (Jaggar, 1945: pl. 2). Before spilling over the wall the flow was diverted for 40 feet along its length. In 1935, a pahoehoe flow from Mauna Loa encountered a similar wall in the Humuula Saddle and formed a pond behind it until the level of the lava became high enough to spill over it, again with almost no effect on the wall itself. In 1954, a pahoehoe flow on the floor of Kilauea caldera surrounded an old corral on three sides, but did not push over its loose stone walls, which actually were in such poor condition that they were starting to tumble down by themselves. In 1950, a rapid aa flow on the west side of Mauna Loa encountered a loose stone wall about 3 feet high along the upper side of the

highway. The lava soon piled up enough to spill over the wall, but it does not appear to have damaged the wall, and for a distance of about 250 feet at the south edge of the flow it spread only 15 to 20 feet beyond the wall. Farther north the same flow continued unchecked down the mountainside (Finch and Macdonald, 1950: 4).

An excellent example of the effect of unsubstantial walls on fluid lava is contained in the following description by Jensen (1907: 653) of the lava flow of 1905 at Matavanu, Samoa:

In portions of the coastal area, as at Toapaipai, where the thickness of the flow is between 10 and 40 feet, the lava has in several instances flowed round buildings of stone, piling itself higher and higher, without crushing in the walls. Such houses are now represented by holes, except where the flow has been sufficiently high to enter by the roof, or sufficiently liquid to . . . flow in through the windows. At one place, near Saleaula, where the lava is between 6 and 10 feet thick, a native house was removed before the stream advanced, but the spot where it stood is now a depression surrounded by almost vertical lava walls and has grass growing on the bottom. This spot was preserved by a ring of stones about 18 inches high, such as the natives make round their houses.

The latter constitutes a remarkable extreme example of the ability of walls to hold back lava flows of depth much greater than the height of the wall. This characteristic will be discussed in more detail below.

Mason and Foster (1953) have described the destruction of a tea house on the rim of Mihara Crater in 1951. As the lava surrounded the building, wooden parts were destroyed by fire and lava which entered through window openings, but the masonry walls withstood the pressure of the flow.

During the 1669 eruption of Mount Etna in Sicily, lava flowed against the ancient city walls of Catania. For several days the walls withstood the lava and diverted it around the

city toward the sea (Sartorius, 1880: 252–253). Eventually the lava broke through a weak part of the wall and flowed into the city. It should be noted, however, that the breach occurred in a part of the wall that lay essentially at right angles to the course of advance of the flow, and hence was acting as a dam rather than as a diversion barrier.

The foregoing illustrations are ample to demonstrate that thin masonry walls, and even ordinary loose stone walls such as are built as fences along land boundaries, commonly are able to withstand the pressure of lava flows without being pushed over. As Mason and Foster (1953) have pointed out, such pressure usually is no more than the hydrostatic pressure that the lava is capable of exerting against the wall (and it will be shown that this is only a portion of the theoretical hydrostatic pressure). In some instances the forward momentum of a flow may result in sufficient pressure to push over ordinary stone walls or even masonry walls. Examples of this are known at Etna. However, even the relatively high velocity of the Kaohe flow during the 1950 eruption of Mauna Loa was not sufficient to disturb materially the loose stone wall along the highway. Fortunately, also, on the gentle slopes in the vicinity of Hilo lava flows are likely to be slow moving, thus reducing essentially to zero the risk of the momentum-pressure of a flow pushing over even a very frail wall.

FIG. 4. Wooden plank set in the path of a pahoehoe flow on the flank of Kilauea volcano on March 13, 1955, diverting the flow.

Had the flow spilled over the divide and entered the valley, it probably would have followed the valley to Kapoho. A former railroad embankment 8 to 10 feet high, currently used as a truck roadbed, lay across the top of the divide. The lava reached that embankment and piled up as much as 15 feet above it, but was deflected southward by it, away from Kapoho. Although the top of the flow stood high above the level of the top of the embankment, the movement of the flow was governed by the lower liquid portion, on which the top was merely carried along. The behavior of the flow in this instance clearly demonstrated that under favorable circumstances

EXPERIENCE WITH BARRIERS DURING 1955 ERUPTION

The most recent attempts to control lava flows in Hawaii by means of walls were made during the 1955 eruption of Kilauea. Accounts of the eruption have been, or will be, published elsewhere (Macdonald and Eaton, 1955, and in preparation).

The first possible need for a diversion barrier arose on the evening of March 3, when a big aa flow from the vents near Puu Kii reached a low divide at the head of a shallow valley that led toward the village of Kapoho.

FIG. 5. Bulldozers constructing an earthen barrier in an attempt to keep lava from reaching the Iwasaki camp during the eruption of Kilauea on March 21, 1955.

the height of a barrier need not be as great as the depth of the lava in order to turn the course of the flow.

The next experience with a barrier came on March 13, when fluid pahoehoe flows were erupted in cleared land adjacent to the Pahoa-Kalapana road. Seizing a favorable opportunity, we placed in the path of one of the advancing flow tongues a wooden plank about 8 feet long, 18 inches wide, and 2 inches thick. The plank was set on edge in nearly vertical position, diagonally to the path of the flow, and held in place by a few loose rocks placed behind it. The intense heat of the approaching flow front prevented us from doing a good job of blocking the plank in place. The lava came in contact with the plank and tilted it back to a somewhat flatter angle, but the lava was turned to one side by the plank, and in spite of the insecure blocking did not push the plank aside (Fig. 4). The plank ignited and burned slowly, but continued to divert the flow for half an hour, until a new tongue of lava approached it by a different path and buried it.

On the morning of March 21 a tongue of a large aa flow entered the head of a small valley that led directly to a small plantation camp owned by Koji Iwasaki. It was obvious that if the lava continued down the valley the camp was doomed. In an effort to divert the flow across the low ridge south of the valley, a wall about 1,000 feet long and averaging about 10 feet high was hurriedly thrown up by bulldozers (Fig. 5) working under the direction of Arthur Lyman of Olaa Sugar Company, with the advice of J. P. Eaton of the Hawaiian Volcano Observatory staff. During the afternoon the flow front reached the barrier, and was successfully turned by it. However, after the flow front had moved only about 50 feet along the barrier the supply of lava was cut off, and that tongue of the flow stagnated.

Later in the eruption another flow tongue came against a different part of the barrier. But again, after the lava had moved along the barrier only a few feet, the flow stopped. Still later flows swept down the mountainside by other routes remote from the barrier and destroyed the Iwasaki camp.

Thus, the Iwasaki barrier was not actually subjected to a critical test. However, it does supply some valuable data on barrier construction. The wall was built by 6 bulldozers (three D-8's, two D-7's, and one TD-14) in less than 4 hours, working in an area of old pahoehoe flows where loose material available for incorporation in the wall was not abundant. At times the bulldozers worked within a few feet of the advancing flow front without trouble, and after the first few minutes without undue worry to the operators. Because of the small amount of space available, the wall was placed at too flat an angle to the course of advance of the flow for best results. Nevertheless, the flow front was successfully turned. The flow piled up to nearly double the height of the wall, but only a few fragments rolled over the wall.

About noon on March 22, Robert Yamada started construction of another series of barriers to try to divert another portion of the flow from his coffee plantation near the coast. The work was done by four TD-24 bulldozers under the supervision of Yamada's son, Donald. The first barrier was placed at much too obtuse an angle to the course of the advancing flow. Moreover, the terrain was not really favorable to the successful operation of diversion barriers. The drainage system is poorly defined, and the slope of the land surface is so low that barriers need to be placed at a very acute angle to the course of the flow in order to provide sufficient grade in the new channel behind the barrier. A plan of the Yamada barriers is given in Figure 6.

At 3:30 p.m. on the same day a tongue of the lava flow was advancing down a road toward the barrier at a rate of about 60 feet an hour, with its front only 260 feet from the growing barrier. It became evident to Curtis Kamai and me that this tongue would reach the barrier before the main body of the flow reached it somewhat farther upslope, and
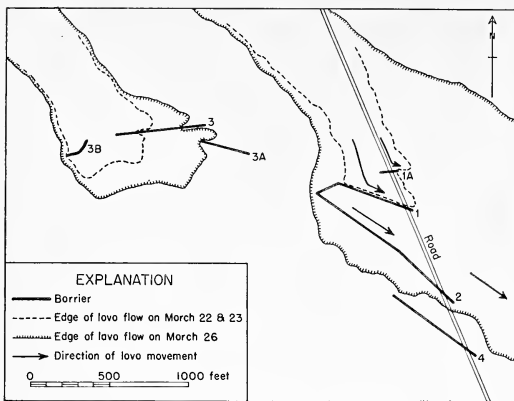
FIG. 6. Plan of the barriers built by Robert Yamada in an attempt to keep lava from destroying his coffee plantation, on March 22–24, 1955.

might consolidate against the barrier to form a dam which would impound the main body of the flow against the barrier and cause it to spill over. To prevent that, a short barrier (Fig. 6, 1A) about 150 feet long and 8 feet high was hurriedly built across the path of the rapidly advancing tongue. This short barrier was completely successful. Part of the flow was diverted eastward by it, but, more important, the advance of the entire tongue was delayed, as had been hoped, until the main body of the flow had made contact with the main barrier farther west and the entire flow front had turned eastward along the main barrier.

On completion of the first two barriers (Fig. 6, 1 and 1A) construction was started on another (Fig. 6, 2) farther down slope and lying at a more acute angle to the course of advance of the flow. Barrier 2 was connected to barrier 1 by a short wall at its western end. This connection was a mistake because it prevented the full operation of barrier 2 and actually forced some lava to flow around its western end, thus partly defeating its purpose. Lava spilled over barrier 1, which as previously stated was built at too obtuse an angle to the path of the flow, and filled the space between barriers 1 and 2. On March 24 a strong flow of lava was observed by Eaton along the north

side of barrier 2 and parallel to it. Some lava spilled over barrier 2, particularly near its western end where it was only about 6 feet high, and joined that flowing around its west end, but the main body of lava was diverted eastward. No lava reached barrier 4 (Fig. 6).

Barriers 3, 3A, and 3B, to the west of barrier 2 (Fig. 6), were poorly conceived and served no useful purpose. In particular, barrier 3B, which appears to have been an attempt to impound a flow tongue by heaping up a wall around it, was wholly ineffective.

In spite of poor placement and hurried, inadequate construction, the principal Yamada barriers were essentially successful. Very little lava passed barrier 2 in the direction of the coffee plantation, and even at the time of poorest operation of the barrier Eaton estimated that the velocity of flow of lava along the north side of the barrier was 5 times as great as that across it. Considering the much smaller depth of material crossing the barrier as compared with that in the channel behind it, this means that probably at least nine-tenths of the volume of the flow was diverted eastward parallel to the barrier.

Unhappily, these courageous attempts at barrier construction on the part of the Yamadas did not prevent the destruction of the coffee plantation. On March 27 another flow passed a quarter of a mile southwest of the barriers, and on March 28 it swept across the plantation and into the ocean.

The Yamada barriers provided some important lessons in barrier construction. In the first place, they demonstrated the amazing rapidity (and correlatively, the surprising cheapness) with which such barriers can be built by modern bulldozers in areas where construction material is abundant. The area was one of fairly recent aa flows, and large amounts of loose aa clinker could easily be pushed up (together with tree trunks and all other debris) into a wall. Careful observation by Eaton, Kamai, and myself revealed no signs of any yielding of the walls under the thrust of the lava flows. The short delaying barrier (Fig. 6,

1A) was entirely successful, and demonstrated one method of controlling the relative speed of advance of different parts of a flow front. Barrier 2 showed that even when the flow top has piled high above the barrier, and some spill-over is occurring, the barrier may still control the direction of movement of the bulk of the flow. The Yamada barriers demonstrated also the importance of a cleared corridor along the upper side of the barrier, to facilitate the advance of the flow along the barrier; the importance of placing the barrier at an acute angle to the course of the flow, and maintaining a continuous downgrade in the new channel created by the barrier; the importance of extending the barriers laterally sufficiently far to be certain of catching all flows that may advance toward the area being protected; and finally, the importance of planning and building in advance, thus avoiding the poor execution attendant on hurried construction with the lava crowding the bulldozers.

As it crossed the Yamada coffee fields, the lava provided yet one more lesson on lava barriers. In clearing the fields, bulldozers had pushed up great heaps of trash, 10 feet or more in height. These heaps consisted largely of trunks and branches of pandanus trees, with smaller amounts of other vegetable debris and some rocks. The lava flowed between, and eventually over, the heaps of loose and mostly light rubbish without to any important degree displacing them, thus again demonstrating the small amount of thrust exerted by lava on obstacles. A similar example occurred earlier in the eruption at the time of the outbreak at the edge of Kapoho village, when a heap of rubbish that had been pushed aside in clearing land diverted the flow away from a house. The Kapoho flow was a thin and very fluid pahoehoe flow, and might be expected to be easily diverted. The flow through the Yamada coffee fields was a very active aa flow with a moving front 10 to 15 feet high, and might be expected to exert as much thrust against an obstacle as almost any Hawaiian flow; yet even it exerted so little thrust that the piles of

loose debris in its path were essentially undisturbed by it.

The fact that lava flows follow the path of least resistance was demonstrated repeatedly during the 1955 eruption. The flow fronts advanced much more rapidly along roads than through adjacent cane fields or forests. Even the small amount of obstruction caused by small and relatively scattered vegetation obviously slowed the advance of the lava. At the Yamada barriers, the lava covered the ground cleared by the bulldozers during construction of the walls much more rapidly than it did the uncleared forest areas. This fact is important because it indicates the great desirability of clearing and keeping reasonably clear a path 500 or more feet wide along the upper side of a diversion barrier to aid in turning the flow and establishing a channel along the barrier.

PRINCIPLES GOVERNING LAVA MOVEMENT

Certain basic facts in the behavior of lava flows are of fundamental importance to the operation of lava barriers. These facts may be briefly enumerated.

Although every lava flow has some solid portions, the movement of the flow is governed by the liquid portions. The solid portions are passively dragged along by the liquid, tending to modify somewhat the behavior of the liquid, principally by making it more viscous; but, especially in Hawaiian flows, these modifications are small. The fact of basic importance is that the flowing lava is essentially a liquid and for the most part behaves like one. Thus lava always tends to flow directly down the steepest available slope, and to follow the path of least resistance.

In aa flows the most fluid portion is restricted to a narrow feeding river, seldom more than 30 feet wide, usually situated near the center of the flow. The margins of active flows commonly are still mobile, but very much less so than the material in the feeding river. Similarly, pahoehoe flows are fed by narrow streams flowing through natural pipes, or lava tubes. The modes of advance of both

types of flows have been described elsewhere (Macdonald, 1953).

The viscosity of lava flows is high. Even in the most fluid portion, close to the vents where the temperature and gas content are highest and the load of solid crystals and rock fragments is least, the viscosity is 300,000 to 400,000 times as great as that of water (Macdonald, 1954: 173). Farther from the vent the viscosity of the most fluid portion rises to a million and more times that of water, and the effective viscosity of the flow as a whole is still higher. The liquid has a specific gravity probably 2 to 2.5 times that of water. Thus the liquid is both heavy and viscous. On steep slopes the heaviness of the liquid results in high speeds of flow, locally up to about 30 miles per hour, in spite of the high viscosity. However, such high speeds are attained only in the narrow feeding channels or tubes. The high viscosity of the lava normally results in slow movement of the main body of the flow. On the steep slopes in central Kona the first flow of the 1950 eruption advanced as a whole at an average rate of 5.6 miles per hour. However, on slopes such as prevail on the side of the mountain toward Hilo the fastest observed advance of a flow front is only about 1,000 feet per hour, and most flow fronts advance much more slowly than that. The flows of 1855 and 1881, on the slope of Mauna Loa southwest of Hilo, advanced only a few tens or hundreds of feet a day on the middle and lower slopes of the mountain.

In almost all instances, essentially the only force causing movement of the flow front is the component of gravity along the sloping surface over which the lava is moving. Because ground slopes in Hawaii generally are low, the component of gravitational force generally is small. This, combined with high viscosity of the liquid, results in the observed slow speeds of flow. In turn, because of their slow movement, lava flows possess very little kinetic energy. Where high speeds occur, the moving liquid may have enough kinetic energy to cause it to dash a few feet up slopes

opposed to the direction of flow, or be thrown a few feet into the air where it encounters obstacles. Such occurrences are comparatively rare, however, and are encountered only on unusually steep slopes in the narrow feeding channels or very close to the vents. They are never encountered at flow fronts more than a very few thousand feet from the vents. Likewise, the viscosity of the lava, though high, is not sufficiently great to permit much thrust on the flow front from lava behind it. Thus Hawaiian lava flows will not advance up hill to any extent, or exert any appreciable impact pressure against an obstacle owing to energy of motion in the flow. A flow front encountering a barrier will not tend to "climb" the barrier to any important extent, nor will it strike against it with any violence. The lava will accumulate behind the barrier until an equilibrium level is attained, just as would water or any other liquid, and if the depth of the lava becomes great enough it will spill over the barrier. But essentially the only pressure exerted against the barrier is a portion of the hydrostatic pressure of the lava in the pool.

Wentworth (1954) has pointed out that, although essentially a liquid, lava does not behave quite like water or other familiar liquids. The difference results largely from the much greater viscosity of lava, and its tendency to freeze, thereby building up and tending to clog its channel, with consequent irregular overflows. This building up of the channel makes possible one type of diversion by aerial bombing, mentioned earlier. The most obvious effect of the high viscosity coupled with the tendency to freeze is the piling up of lava to form a broad mound instead of a thin sheet, as water would do. The margins of flows are abrupt scarps several feet or tens of feet high. The effect is confined largely to the flow edges. Most flows have broad nearly level (though irregular) tops, determined by the essential attainment of liquid equilibrium. The effect of viscosity and freezing at the edge of the flow, allowing the flow to stand as a self-contained unit with steep margins, is im-

portant in the operation of lava barriers in greatly reducing the hydrostatic pressure exerted against a barrier. Actually, the thrust against a barrier as a result of hydrostatic pressure is only a small fraction of what it would be if the lava were a completely liquid pool with the fluidity of water.

The ability of even loose stone walls to withstand the pressure of flows indicates that the full theoretical amount of hydrostatic pressure is not exerted laterally by the flow. Calculations indicate that with fully liquid lava resting against a wall of loose rock, sliding of the wall would result when the depth of the liquid against the wall slightly exceeded the thickness of the wall. Commonly, however, a lava flow piles up behind a wall to a depth several times as great as the thickness of the wall without displacing the wall. Apparently the departure of the fluid lava from complete liquidity is sufficiently great to prevent the full theoretical hydrostatic pressure within the flow from being transmitted to the forward edge. This is further confirmed by the frequently observed tendency for a flow to stop with only its lowermost edge in contact with some natural obstacle, such as a crater wall, leaving a moat a few feet wide between the obstacle and the higher part of the flow margin.

FACTORS INFLUENCING EFFECTIVENESS OF BARRIERS

The tendency of lava to build up its channel to a high level is important to the operation of lava barriers in two respects. One is the possibility that the flow may build up so high as to spill over the barrier. There is little danger of this if the angle of the barrier to the flow course is not too great—that is, if the barrier does not force the flow to turn too sharply. A little spill-over may be expected in any case, but is unimportant if most of the flow turns and follows the barrier. Experience at the old railroad embankment near Kapoho and at the Yamada barriers, in 1955, clearly indicates that the lower part of the flow largely controls the

direction of movement of the whole flow. A well-placed barrier can be confidently expected to turn the initial flow of a group, even though it is considerably thicker than the barrier is high. Once the flow is turned, the main channel will develop parallel to the barrier, but probably several tens of feet distant from it because of the cooling effect of the barrier and frictional retardation of the edge of the flow against the barrier.

If the flow continues for a long period, the walls confining the main channel may build up to form natural levees rising to a level higher than the barrier. A breakdown of the levee could then release a flood of lava over the barrier, possibly establishing a new flow course over the barrier in addition to, or even instead of, that parallel to the barrier. Such breakdowns and lateral floodings are common near the vents, especially on steep slopes and where the channel makes an abrupt bend, but they are very rare on well-established flows at a distance from the vents. Provided the angle of the barrier to the natural flow course is kept small, the danger of such a breakdown of the channel levee at a barrier distant from the vents is very small.

More probable is a breakdown of the levee near the vents, far up slope from the barrier, producing a new major tongue of the flow. In early stages of eruptions this is a common event, and it sometimes occurs even in late stages. It may pose by far the greatest threat to the success of a lava barrier. If the new flow tongue encounters the barrier on the upslope side of the older tongue, which is already against the barrier, it may be impounded between the barrier and the older tongue, accumulate until it overtops the barrier, and flow on down the mountainside. The effectiveness of the barrier is then partly or wholly lost (although it may continue to divert the first tongue and thus reduce the amount of lava advancing toward the area under protection). Fortunately, it is rare that more than one flow tongue reaches a distance from the vents as great (12 or more miles) as that of the pro-

posed main Hilo barrier from the active part of the Mauna Loa rift zone. Once a tongue reaches that great a distance from the vents it generally is well established as the principal flow tongue of the eruption. But the possibility of a second tongue reaching the barrier up slope from the first must be kept in mind, and, if possible, means must be provided to cope with it.

BARRIERS PROPOSED FOR HILO AREA

Barriers Proposed in 1937. The positions of the barriers suggested by Jaggar (1937, 1945) are shown in Figures 1 and 7. The principal barrier was to start at the Wailuku River a short distance above the Pukamaui Falls (where the principal intake of the Hilo water system is located), extend 4 miles east-southeastward, then turn and extend 5 miles east-northeastward, ending about a mile south of the shore at Keaukaha. This proposed barrier was intended to divert southward any lava flows approaching Hilo along the Wailuku Valley or down the slope of Mauna Loa north of the Waiakea Homesteads. Two other shorter proposed barriers were located higher on the mountainside. One extending northwestward from the vicinity of Puu Ulaula, at 10,000 feet altitude on the northeast rift zone of Mauna Loa, was intended to divert westward flows originating on the rift zone above Puu Ulaula. The other, extending south-southeastward from near Puu Huluhulu, in the Humuula Saddle, was intended in effect to shift the Humuula divide farther east so that flows pooling in the flat area just south and west of Puu Huluhulu would spill westward instead of eastward toward Hilo.

The plan adopted in the report of the District Engineer, U. S. Engineer Department, closely resembled the original recommendations by Jaggar. The barrier close to Hilo was to be 46,750 feet long, varying in height from 20 to nearly 80 feet, with a flat top 5 feet wide and slopes of 45°. It was to be built largely of material available at the site. At stream crossings a cluster of concrete pipes of 48-inch di-

ameter laid through the barrier would allow water to pass, but molten lava entering the pipes would quickly chill in them and solidify, plugging them. At highway crossings concrete underpasses were provided, which could be blocked with concrete stop logs when a lava flow approached. For further details of the proposed construction the reader is referred to the paper by Jaggar (1945), and the unpublished report of the District Engineer. For convenience of reference, some of the drawings of construction design are reproduced in Figure 8.

Barriers Proposed in 1950. Following the 1950 eruption of Mauna Loa, concern again increased in Hilo over the possibility of damage to the city by lava flows, and Finch and I undertook a restudy of the barrier proposal. As a result of the study, we were more than ever convinced that barriers would be effective. However, because of the growth of Hilo in recent years, we suggested that the position of the proposed barrier might be shifted southwestward from that previously advocated. The positions of both lines are shown in Figure 7. The new proposed barrier would consist of several segments. The upper and principal segment would extend from the Wailuku River at approximately 3,900 feet altitude east-southeastward about 12.6 miles to a point where the lava flow would be guided down slope by a natural drainage channel. Farther seaward other shorter barriers would direct the flow into forest land southeast of Hilo where natural topography would lead it away from Hilo city, harbor, and airport. The total length of the newly proposed barriers is approximately 17 miles, as compared to 8.85 miles for that proposed in 1940. The new line extends south of Kaumana and the Waiakea Waena suburb of Hilo, which lie outside the barriers of the earlier scheme. It also provides more complete protection for the Hilo Airport area and the Keaukaha suburb, and protects the drilled wells east of the airport, which in time of eruption might provide the major source of water for the city.

The lines indicated in Figure 7 for the course of the newly proposed barriers are intended only as suggestions of an approximate route. Their precise position should be determined by detailed surveys like those made by the U. S. Engineer Department for the route of the earlier proposed barrier.

The route laid out by that department in 1940 takes complete advantage of natural topography and crosses the contour lines at the maximum possible angle. It would protect the harbor and the central part of the city as completely as the alignments suggested in 1950. Only if it is considered economically justified to protect a larger area are the positions suggested in 1950 to be preferred.

The lines on the map show the main barrier as continuous walls, as was the barrier recommended by the U. S. Engineer Department in 1940. An alternative construction, suggested by Eaton (personal communication, 1956), is a series of short segments set en echelon to each other as shown in Figure 9A. This design would provide possible means of confining portions of the flow that may spill over any

one segment of the barrier, by extending a lower segment to a point beyond the spill-over. Figure 9B illustrates the way this might be done. It should be noted, however, that it might not be possible to force the spill-over into the channel behind the lower barrier segment if the space behind that segment had already been occupied by an earlier portion of the flow. If the barrier is constructed in short echelon segments, it should be started higher up the Wailuku River than indicated in Figure 7, possibly as high as 6,400 feet (about 2 miles east of Puu Huluhulu), to avoid building the segments at a greater angle to the natural direction of flow than would be a continuous barrier and thus actually increasing the likelihood of a spill-over. The idea warrants careful consideration in relation to topographic studies of greater detail and precision than are possible on existing base maps.

Wentworth (unpublished communication, 1955) has suggested that complete reliance be placed on hurried construction of a barrier after a flow has actually started to advance on Hilo. Experience during the 1955 eruption
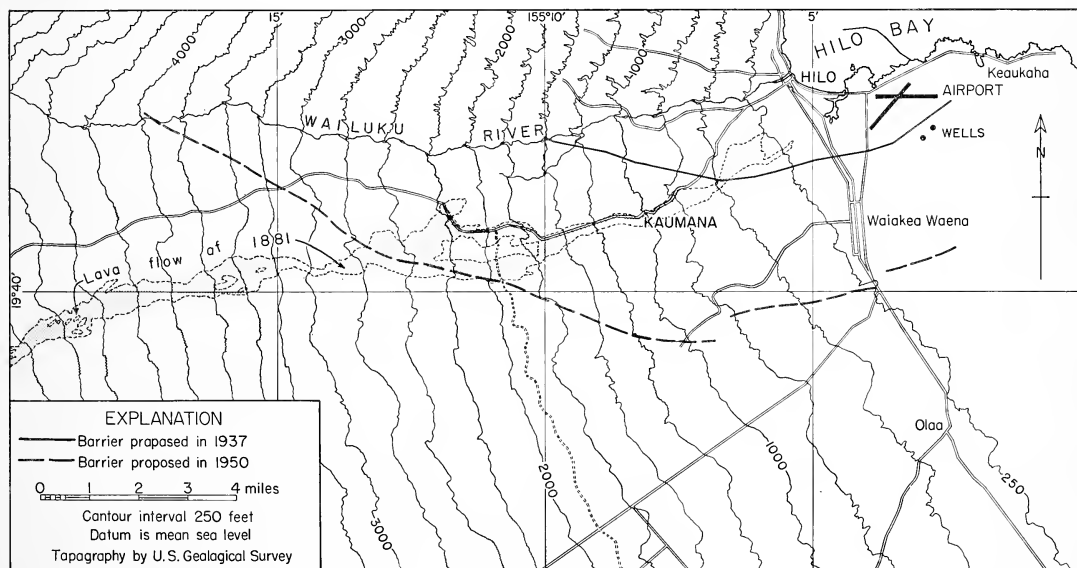
FIG. 7. Map of the area in the vicinity of Hilo, showing the route of the barrier proposed by Jaggar in 1937 and surveyed by the U. S. Engineer Department in 1940; and that of the barriers proposed by Finch and Macdonald in 1950. The latter route is only approximate.
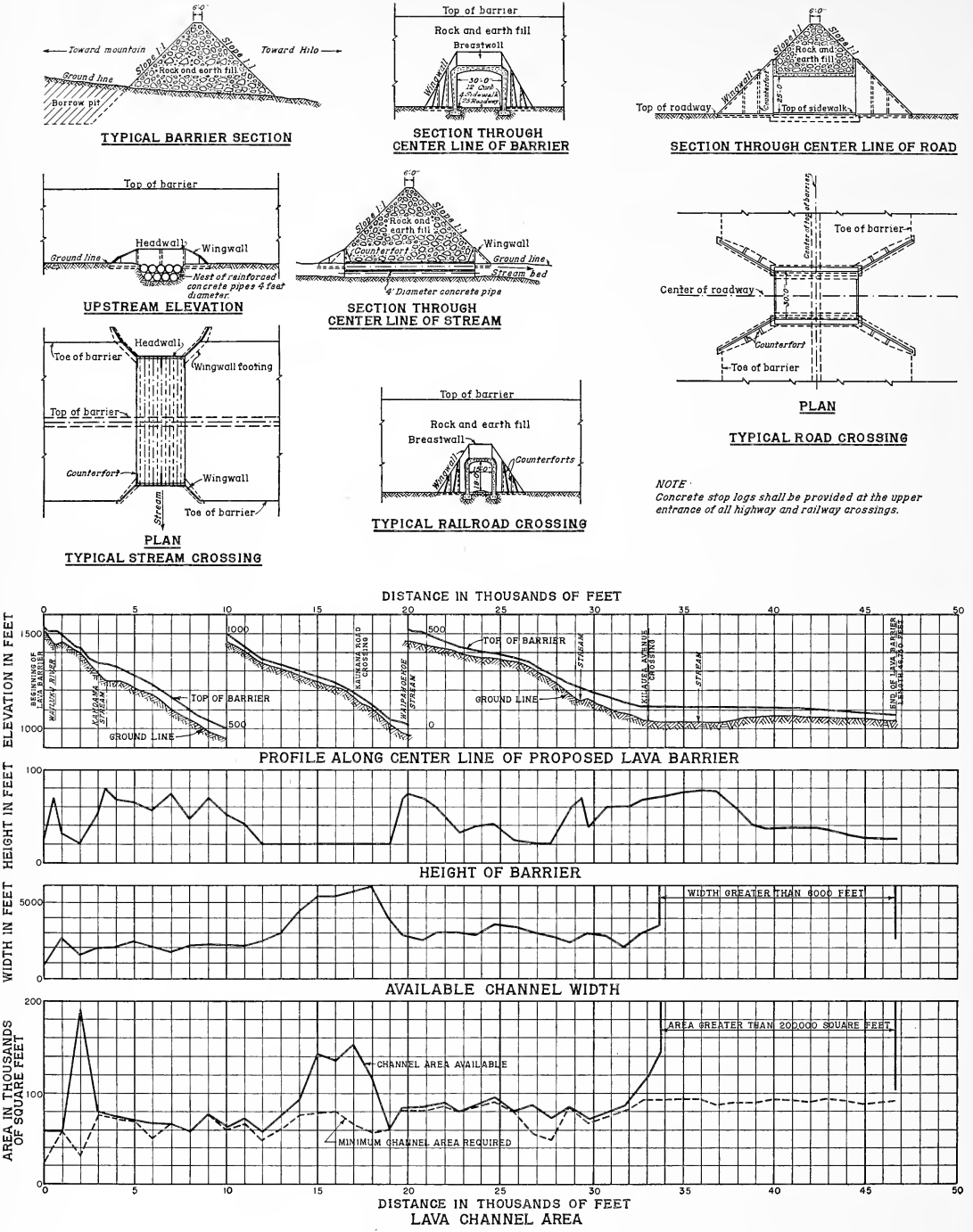
FIG. 8. Drawings showing construction design, ground profile, height, channel width, and channel volume of the barrier designed by the U. S. Engineer Department in 1940. (After Jaggar, 1945, figs. 3, 4.)
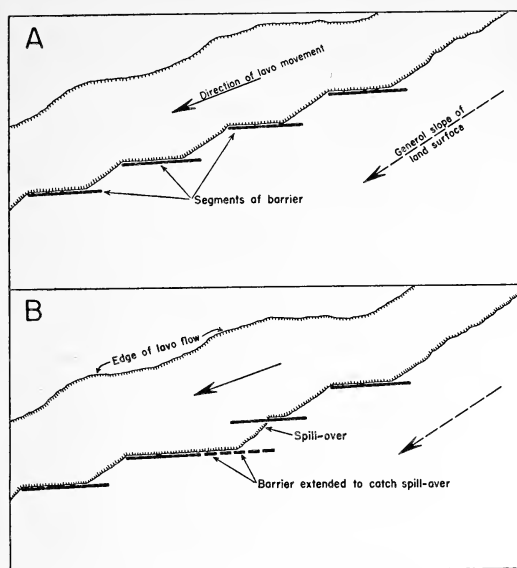
FIG. 9. A, Diversion barrier consisting of a series of short segments set en echelon. B, Manner in which one segment might be extended to catch a spill-over from the previous segment.

indicates that this is not an impossibility. It is, however, less desirable than the construction of a barrier well in advance of the need, because work done under such urgent circumstances is likely to be less well done. Time may not be sufficient to finish the job properly, and it is possible that a flow such as that of 1859 might descend the mountain so rapidly that the barrier could not be built at all. At any rate, if such emergency construction is to be relied upon, plans should be carefully prepared and a route for the barrier chosen, so that work can be started without delay or uncertainty when the need arises, and the barrier can be placed properly for maximum efficiency. Construction of the barrier should be started at its upper end, at a point determined by the course being followed by the flow, and work should progress down slope ahead of the flow.

Also, it has been suggested that a network of roads spaced about a mile apart in the area of proposed barrier construction be prepared

in advance and kept clear and trafficable; but such a network appears unnecessary. Instead, a truck trail might be opened by bulldozers along the route of the barrier itself, both to serve as an access route and to mark clearly the line along which the barrier should be built when the emergency arises. Even if construction of the barrier is deferred, the route it is to follow should be marked as soon as possible so that under emergency conditions construction can proceed with minimum delay and along the correct line.

Present Views on Construction Methods. Developments in construction machinery, and experience with barrier construction and operation during the 1955 eruption, have made it apparent that barriers can be built much faster and cheaper than previously believed. Actually, the barrier need consist only of an elongated heap of rubble, obtained locally and pushed into place by bulldozers. Rock fragments should predominate, but soil and plant debris, even large tree trunks, may be incorporated. The use of excessive amounts of vegetable materials probably should be avoided in a barrier built in advance of the eruption, because such material will eventually rot away and allow the heap of rubble to slump, possibly requiring repair of the barrier.

There is no need of maintaining side slopes of 45°, or of careful dressing or smoothing of the slopes. Loose material pushed up to the required height will settle into equilibrium slopes probably between 30° and 40° from the horizontal. Such slopes are wholly saitsfactory so far as performance of the barrier is concerned. For convenience in construction, it may be desirable to build the uphill slope somewhat flatter, so that the bulldozers can convey their loads to the top of the barrier more easily.

The material for construction should be obtained entirely on the upslope side of the barrier. This has the advantage of somewhat deepening the channel created on the uphill side, for any given height of wall; and just as important, of clearing a wide swath (at least

500 feet wide) along the barrier to provide a path of easy movement for the lava.

No better design for stream crossings has been found than that suggested by the U. S. Engineer Department in the 1940 report. A bundle of concrete pipes 24 to 48 inches in diameter should be laid parallel to the stream course, and anchored in place with concrete. Above these, the barrier may consist of the same loose rubble as elsewhere.

Concrete underpasses, with concrete stop-logs, have been suggested by the department for highway crossings. An alternative, and much less costly method, would be to leave a gap in the barrier for the highway to pass through, and provide a pile of loose rubble near one side of the gap that can quickly be pushed into place by bulldozers, thus closing the gap when the flow approaches it. One advantage of the barrier proposed in 1950 (Fig. 7) is that no special crossing structure is required at the highway between Hilo and Olaa. One segment of the barrier ends just up slope from the highway, natural topography then guiding the flow across the highway to a point where it will be controlled by the next segment.

A flat top on the barrier is unnecessary, though it would do no harm. It has been suggested that the barrier might be built with a flat top broad enough to accommodate either a one- or two-lane highway. However, this would add greatly to the cost, both because of the much greater bulk of material that would have to be obtained and put in place, and because of the higher standards that would have to be set for the material and the greater care that would have to be used in construction. To successfully divert lava flows, the barrier need not even approach the standards necessary for a highway fill.

The precise height of barrier needed can be determined only by detailed surveys. The barrier must be higher than average where it crosses depressions, but can be lower where it is superimposed on natural ridges. The height of the barrier designed by the U. S. Engineer Department in 1940 averaged about 40 feet

for an available channel width throughout most of its course of approximately 3,000 feet. The height was determined by the cross-sectional area of the channel behind the barrier that was considered necessary to contain a lava flow of the dimensions that might reasonably be expected to enter the area. Logically enough, the problem was approached on the basis of hydrodynamics, assuming that the lava would behave much like a stream of water under the same circumstances. As noted earlier, however, we now realize more clearly that lava does not behave wholly like water. The sides of the flow rise steeply to heights of many feet above the surrounding terrain or above a restraining barrier. It is therefore not necessary to build a barrier to a height equal to the full depth of the lava flow it is intended to divert. I believe that a barrier with an average height of 25 to 30 feet following the 1940 alignment would be adequate.

CONCLUSIONS

As a result of the foregoing considerations, I believe (1) that lava flows are certain to enter the city and harbor of Hilo eventually unless something is done to prevent their entry; (2) that they can be successfully diverted from the city and harbor by properly located and constructed barriers; (3) that no other method can be relied upon to divert the flows; (4) that construction of the barriers in advance of the eruption is preferable, but that barriers probably can be constructed in time even after the flow has started to advance toward Hilo; (5) that the barriers need consist only of loose rubble obtained locally and pushed into place by bulldozers; and (6) that the barrier alignment proposed by the U. S. Engineer Department in 1940 is adequate to protect the center of the city and the harbor, but an alignment farther southwest is necessary if it is desired to protect all of the city.

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NEWS NOTES

Index to Plant Chromosome Numbers

The need for up-to-date coverage of the literature dealing with plant chromosome numbers has led to an undertaking designed to compile and publish in annual installments a chromosome index for the entire plant kingdom.

This is being done by a group of botanists who are reviewing some two hundred journals and are listing all original chromosome counts occurring therein, except those resulting from endopolyploidy or deviating because of experimental treatment.

The first issue, in part supported by a grant from the University Research Council of the University of North Carolina, will be ready for distribution in May, 1958. It will cover the 1956 journals, from which over 2,000 listings have been taken. It is being produced by offset process, 8½ x 11 inches, on paper punched for loose-leaf binders. The price is $1.00. Advance orders would be helpful in determining the number of copies to print. Orders *must* be accompanied by payment and may be sent to C. Ritchie Bell, Department of Botany, University of North Carolina, Chapel Hill, North Carolina.

International Oceanographic Congress

The American Association for the Advancement of Science, in cooperation with UNESCO and the Special Committee on Oceanic Research of ICSU, is planning and organizing an International Oceanographic Congress to be held during the period from 30 August to 12 September 1959 at the United Nations Building, New York. The Congress will be devoted to the fundamentals of the marine sciences rather than to their applications, and will be centered around five symposia on the oceans:

1. The history
2. The boundaries
3. The deep sea
4. Dynamics of organic and inorganic substances
5. The marine life regime

Each topic for a symposium will be considered for two consecutive days. Three invited lectures will be given each morning. The afternoon sessions will be organized around the morning topics, either in round-table discussions, in seminars, or in a series of papers. Several groups may run concurrently. Papers for the afternoon sessions will be selected from those received in response to this and subsequent announcements. Not all papers which have been accepted will actually be presented, but all accepted papers will be available at the meeting in mimeographed form. Titles and abstracts should be submitted as soon as possible and in no case later than 1 February 1959. The completed papers must be submitted by 1 May 1959 in order to allow time for duplication and distribution to the participants in the afternoon meetings well in advance of the meeting. All papers must have an abstract in a second language of the Congress. Papers may be presented in English, French, German, Russian, or Spanish. Simultaneous translations will be available for at least some of these languages.

The organizing committee expects that contemporary advances in the marine sciences, rather than reviews of older published work, will be presented under these broad topics. It is hoped that the younger staff members of the various oceanographic laboratories around the world will be encouraged to attend and to take part in the Congress. In order to assist with their attendance, the committee hopes to obtain funds to help defray the travel expenses of these younger participants. The committee also hopes to be able to contribute towards the travel expenses of the invited speakers at the morning sessions.

This notice should be considered as preliminary. Until further notices are issued, titles and abstracts of papers, which are publicly solicited by this notice, and any other correspondence should be sent to:

Dr. Mary Sears, Chairman
Woods Hole Oceanographic Institution
Woods Hole, Massachusetts, U.S.A.

utively numbered in upper right-hand corner. Sheets should not be fastened together in any way, and should be mailed flat. Inserts should be either typed on separate sheets or pasted on proper page, and point of insertion should be clearly indicated.

Original copy and one carbon copy of manuscript should be submitted. The author should retain a carbon copy. Although due care will be taken, the editors cannot be responsible for loss of manuscripts.

Introduction and summary. It is desirable to state the purpose and scope of the paper in an introductory paragraph and to give a summary of results at the end of the paper.

Dictionary style. It is recommended that authors follow capitalization, spelling, compounding, abbreviations, etc., given in *Webster's New International Dictionary* (unabridged), second edition; or, if desired, the *Oxford Dictionary*. Abbreviations of titles of publications should, if possible, follow those given in U. S. Department of Agriculture *Miscellaneous Publication 337.* Examples of the usual abbreviations are to be found in *Pacific Science.*

Footnotes. Footnotes should be used sparingly and never for citing references (see later). When used, footnotes should be consecutively numbered by superior figures throughout the body of the paper. Footnotes should be typed in the body of the manuscript on a line immediately below the citation, and separated from the text by lines running across the page.

Citations of printed sources. All references cited should be listed alphabetically by author at the end of the paper, typed double-spaced. References to books and to papers in periodicals should conform to the following models:

BATZO, RODERICK L., and J. K. RIPKIN. 1849. *A treatise on Pacific gastropods.* vii + 326 pp., 8 figs., 1 map. Rice and Shipley, Boston.

CRAWFORD, DAVID L. 1920*a.* New or interesting Psyllidae of the Pacific Coast (Homop.). *Ent. News* 31 (1): 12–14.

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In the text, sources should be referred to by author, date, and page, as follows: "It was noted (Rock, 1916: 18) that . . ." or "Rock (1916: 21–24) says . . ."

Quotations. Quoted matter of fewer than five printed lines (about 200 characters) should be given in the text in the usual form, using double quote marks. Longer quotations should be set flush with left margin. The author is responsible for the accuracy of quoted material.

Numbers. Decimals, measurements, money, percentages, time; enumerations in which any figure is 10 or over; and isolated enumerations of 10 and over should be given in Arabic figures, rather than spelled out, except when the number begins a sentence.

ILLUSTRATIVE MATTER

Only the minimum number of illustrations required to supplement the text will be accepted by the editors. Reproduction costs of illustrations in excess of the number allowed by the editors will be paid by the author.

Illustrations should accompany manuscript, on separate sheets. Often more valuable than a photograph is a good line drawing, which may be reproduced by the zinc etching process.

Figures and graphs. Copy for figures and graphs should always be drawn large enough to allow for at least one-third reduction by the engraver. Copy should consist of carefully prepared line drawings in one color only, drawn in India ink on plain white drawing paper or tracing cloth. Co-ordinate paper with lines in light blue (a color which will not show in a photograph) may be used; but co-ordinates which should appear in the finished graph must be drawn in India ink. If original figures may not be conveniently submitted with manuscript, duplicate rough sketches or photographic prints may be furnished to aid the editors in their decisions.

It is strongly urged that an indication of scale be incorporated as a part of all drawings in which magnification and size are critical considerations.

Photographs. Photographs should be chosen for clarity in portraying essential information. They should be printed for contrast, on glossy paper, and should be sent unmounted. They should be identified with serial number written in soft pencil on the back to correspond with list of captions.

Illustrations will be returned to the author.

Tables. Tabular matter should be kept to a minimum. Each table, prepared to conform with *Pacific Science* style, should be typed on a separate page, and its position indicated on the manuscript.

Captions. Readily identifiable captions for figures, graphs, photographs, and other illustrative matter should be supplied on a separate page.

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Proof should be corrected immediately and returned. *at once* to Mrs. Marion P. Goddard, assistant to the editors. Authors are reminded that the editors will allow only a minimum number of corrections on galley proof. Additions to the printed text and changes in style and content are not permitted.

All queries on proof should be answered. If corrected proof is not received within four weeks after being sent to the author, author's changes cannot be accepted.

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U P H

PACIFIC SCIENCE

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AND PHYSICAL SCIENCES OF THE PACIFIC REGION

UNIVERSITY OF HAWAII PRESS

SUGGESTIONS TO AUTHORS

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Manuscripts will be acknowledged when received and will be read promptly by members of the Board of Editors or other competent critics. Authors will be notified as soon as possible of the decision reached.

Manuscripts of any length may be submitted, but it is suggested that authors inquire concerning possibilities of publication of papers of over 30 printed pages before sending their manuscripts. Authors should not overlook the need for good brief papers, presenting results of studies, notes and queries, communications to the editor, or other commentary.

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PACIFIC SCIENCE

A QUARTERLY DEVOTED TO THE BIOLOGICAL AND PHYSICAL SCIENCES OF THE PACIFIC REGION

Previous issue published July 10, 1958

CONTENTS

Soils and Agriculture of the Palau Islands[1]

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Soils of the Palau Islands range from deeply weathered Latosols[3] to shallow, rocky Lithosols, and include Regosols, Alluvial Soils, and Organic Soils. Most extensive in the islands are the Latosols, of general interest because of their wide distribution in the humid tropics. Associated soils are much less extensive but are more important to local food production. The latter also illustrate effects of local factors in soil formation. Data on characteristics, distribution, and utilization of the soils and a preliminary evaluation of their agricultural potentialities are given in this paper. More complete descriptions of the soils are part of a comprehensive report on the geology and soils of the islands now being prepared for publication as a professional paper of the U. S. Geological Survey.

GEOGRAPHIC SETTING

Location and Extent

Most western group of the Caroline Islands, the Palau chain is almost directly south of Tokyo and due east of Mindanao. Location of the group in the western Pacific Ocean is shown in Figure 1. Lying 7° north of the equator, the Palaus are in the same latitude as Colombia and Venezuela.

The Palau chain stretches approximately 50 miles, from Kayangel at the north to Angaur at the south. From east to west, the dimensions of the chain range from 3 to 25 miles, as measured to the outer barrier reefs.

The total land area of the group, which consists of some 350 closely spaced islands and islets, is 175 square miles. Babelthuap, largest island in the group, has an area of almost 140 square miles. The bulk of the remaining land area is distributed among eight additional islands. Most of the 350 islands and islets of the chain are tiny reefs or bars, barely above sea level.

Physiography and Topography

The four types of islands in the Palau group are reef and atoll islands, platform islands, high limestone islands, and volcanic islands (Tayama, 1953). The reef and atoll islands, by far the most numerous, are flat land surfaces only a few feet above sea level. Examples of this type are Kayangel atoll at the north end of the chain and the many small unnamed reefs and atolls north of Peleliu. The platform islands, also mainly flat, are a little higher than the reefs and atolls. Angaur and Peleliu are chiefly of this type, though part of each consists of limestone ridges. The high limestone islands rise steeply out of the sea and are mostly narrow and elongated in shape. A few have the form of mushrooms. The principal high limestone islands are Urukthapel and Eil Malk; these and the numerous small ones all lie between Koror and Peleliu, approximately 25 miles apart. Parts of
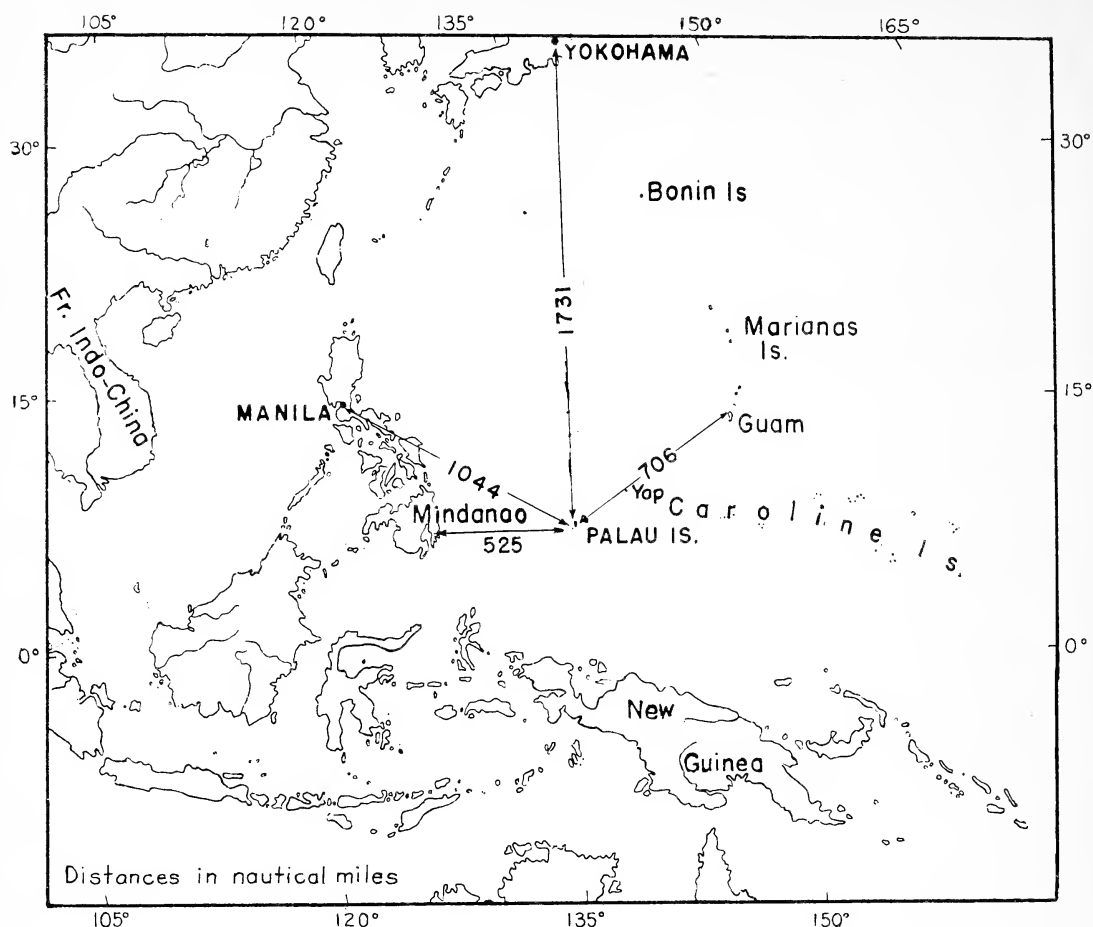

FIG. 1. Map showing the location of the Palau Islands in the western Pacific Ocean.

Peleliu, Angaur, and Koror and much of Auluptagel are also high limestone ridges. The maximum elevation of the high limestone islands is 686 feet above sea level on Uruk-thapel. Slopes of these islands are generally steep or very steep though a few have small central depressions with mild relief.

The volcanic islands, so named because of the underlying basement rock, are generally hilly to rolling with local relief commonly measurable in tens of feet. Slopes and ridge crests are rounded and subdued. Babelthuap has three prominent ridges running roughly parallel to the long north-south axis of the island. The highest elevation in the Palau Islands is that of 794 feet above sea level on

one of the ridges in northwestern Babelthuap. The volcanic islands (Babelthuap, Arakabe-san, Malakal, Auluptagel, and Koror) are all closely grouped in the northern part of the chain. As mentioned earlier, Auluptagel and Koror are partly volcanic rock and partly limestone.

Soil Parent Materials

The variety of rocks from which soils have been derived is relatively small in the Palaus. The platform and high limestone islands consist of former coral reefs. The present surface of the high limestone islands is largely a mass of rubble of assorted sizes. Much of the land surface of the platform islands also consists

of rubble, commonly small in size. The principal volcanic rocks range from olivine-augite basalts to silicic hornblende dacites (Corwin, 1951) identified as andesitic agglomerates by Japanese geologists (Tayama, 1953) and also known as basaltic and andesitic volcanic breccias. Associated with the flow rocks and agglomerates on Babelthuap are some basic volcanic tuffs. Interbedded sedimentary clays and lignite comprise the surface formations in a few places in western and southeastern Babelthuap.

The distribution of rocks on the Palau Islands is strongly reflected in the distribution of soils (Fig. 2). Rocks of volcanic origin are parent materials for most of the Latosols. Some latosolic soils have also been formed from interbedded sedimentary clays. Deep soils with distinct horizons have not been formed from limestones, most of which have rubble surfaces. Where the volcanic rocks are exposed on steep or moderately steep slopes, shallow rocky Lithosols have been formed. Deep unconsolidated materials of recent origin have given rise to Regosols, Alluvial Soils, and Organic Soils.

Climate

Typical of the humid tropics, the islands have heavy annual rainfall and high mean temperatures with small seasonal differences (U. S. Dept. of Commerce, 1953). The islands also have rather steady winds, lying as they do in the trade-wind belt. The mean annual precipitation is 148 inches, with a maximum of about 19 inches in July and a minimum of nearly 8 inches in March. On the average, at least 15 days of each month have 0.04 inch or more of rain, whereas 7 days in July have 1 inch or more. The average relative humidity is 82 per cent, with a low of 79 per cent in March and a high of 83 per cent in July, November, and December. The mean annual temperature is 81° F. The maximum and minimum mean monthly temperatures are but one degree higher and lower, whereas the diurnal

variation is about ten degrees. Prevailing winds are from the northeast and east from November to June and from the south and southwest for the remainder of the year.

Vegetation

The native vegetation (Fosberg, 1946) in the Palau Islands was rain forest, which remains in only a few places on Babelthuap. The rain forest consists of large trees, including *Parinarium*, *Campnosperma*, *Couthovia*, *Cynometra*, *Dysoxylum*, *Ficus*, *Semecarpus*, *Randia*, *Fagraea*, *Pittosporum*, *Schefflera*, *Horsfieldia*, and many others. Growing also in the rain forest are such palms as *Pseudopinanga* and *Exorrhiza;* an occasional slender *Pandanus;* such climbers as *Freycinetia*, *Canavalia*, *Piper*, aroids, and *Ipomoea;* also ferns, orchids, and other epiphytes. On both the low and high limestone islands, vegetative cover consists mainly of small to medium-sized trees and shrubs because moisture conditions are unfavorable for plant growth.

The most extensive vegetative type today is anthropic savanna consisting of coarse grasses, weeds, and occasional shrubs. Common genera in the savanna are *Ischaemum*, *Paspalum*, *Digitaria*, *Miscanthus*, *Lycopodium*, *Nepenthes*, and *Pandanus* (Fosberg, 1946). Soils of extremely low fertility support almost pure stands of a fern, *Gleichenia linearis*.

SOILS

The general character and distribution of soils were determined through a reconnaissance survey, according to procedures already described (Simonson, 1953; Soil Survey Staff, 1951). This reconnaissance survey was part of a program of soil and geologic investigations in the western Pacific Ocean (Simonson, 1953). How the soils were being used was observed during the field mapping from March through August, 1948.

Distribution of the soils and land types of the islands is shown in Figure 2. The map units are either soil associations or miscel-
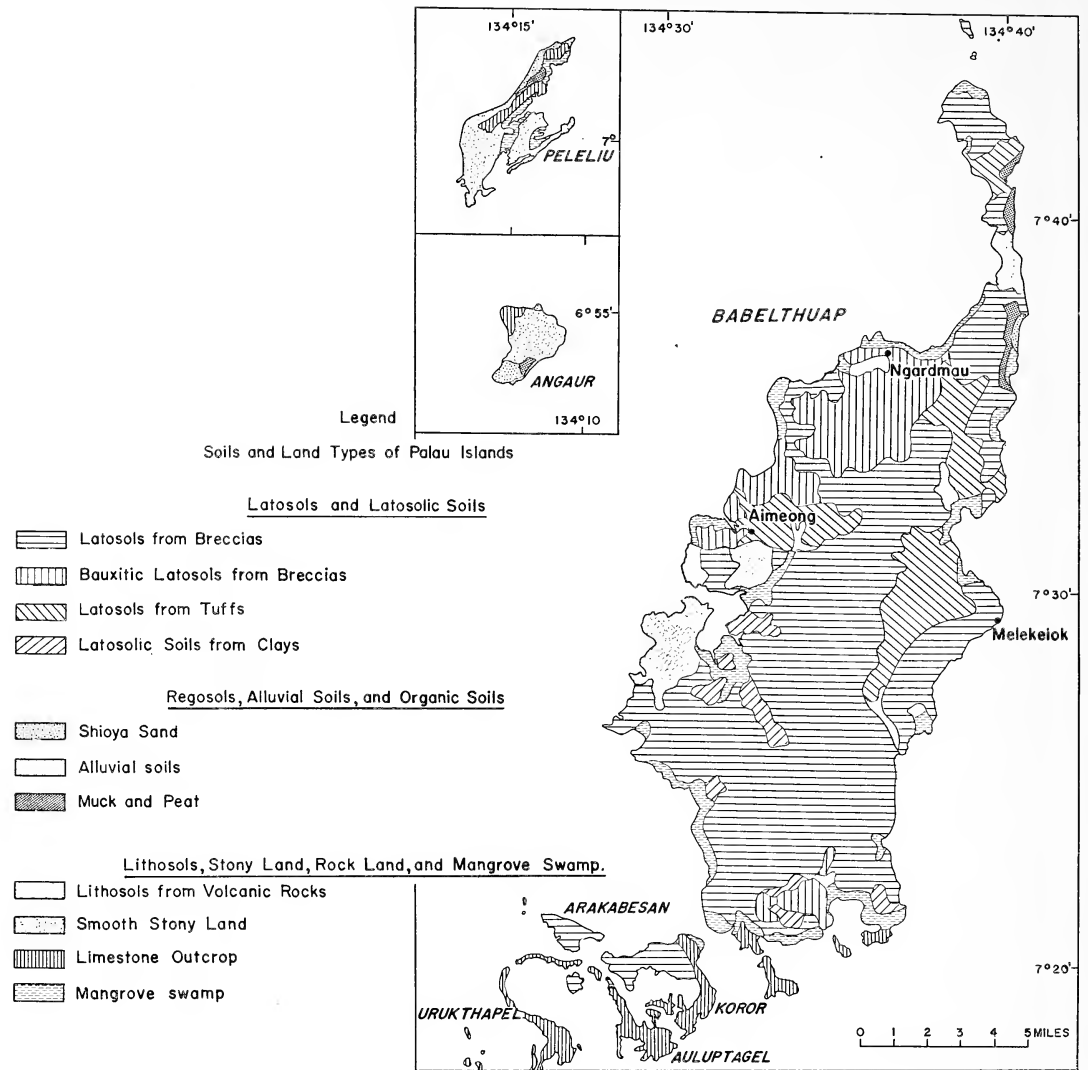
FIG. 2. Map showing the distribution of major soil associations and miscellaneous land types of the Palau Islands. High limestone islands and others that are not inhabited and consist of a single miscellaneous land type are not shown. Angaur and Peleliu, which are at the south end of the chain, are shown by inset maps.

laneous land types, with one exception— Shioya sand, a soil type.

Each soil association consists of one or more geographic areas with a restricted combination of soil types occurring together in a characteristic and repeating pattern. The individual soil types in each association have not been described and identified, however, as they would be in detailed surveys. The component soils in each association are classified

into great soil groups or suborders.[4] Each association is then named for the dominant great soil group or suborder. The associations are described by listing the component soils

[4] The classification system followed in this paper is the one outlined by Baldwin, Kellogg, and Thorp (1938) as modified in a group of papers in *Soil Science*, Vol. 67, No. 2, February 1949, with two exceptions. The term and concept of "Latosol" as proposed by Kellogg (1949) are used. The term "Organic Soils" is used as a substitute for "Bog Soils."

and their approximate proportions. Patterns of occurrence of component soils also may be indicated. The component soils are described either by giving full morphological details for representative profiles together with data on topography and other features or by comparisons with soils that have been fully described.

Miscellaneous land types are geographic units without classifiable soils or with low proportions of such soils. Examples in the Palau Islands are smooth stony land and limestone outcrop. Stray patches of classifiable soils occur in each of these units but comprise a negligible portion of the total area.

The profile descriptions use horizon concepts and terminology as given in the *Soil Survey Manual* (Soil Survey Staff, 1951), unless otherwise stated. The identification of field textures, i.e., apparent texture as determined by the fingers when the profile was being described, is given for individual horizons. Pinholes refer to pores that are 1 mm. or less in diameter, whereas wormholes are tubular channels about 3 mm. in diameter. Numbers of pinholes, wormholes, roots, stone fragments, and concretions are indicated by three relative classes, viz., few, common, and many. Concretions are roughly spherical, unless otherwise noted, and their sizes are referred to the same limits as granular structure (see *Soil Survey Manual* for these size limits).

Each profile description is preceded by a brief statement on the geographic setting, and some are followed by comments not readily included in the description itself.

Latosols and Latosolic Soils

The Latosols are by far the most extensive soils in the Palau Islands, comprising some 60 per cent of the total land area. As shown by the map in Figure 2, they are dominant on Babelthuap, Koror, Arakabesan, and Malakal, and form the north tip of Auluptagel. Despite their large acreage, however, they have limited importance to local food production.

The Latosols of the Palaus are well drained, red to yellowish, friable, strongly acid, deep, and ferruginous or bauxitic soils derived mainly from volcanic rocks. The regoliths from volcanic rocks are weathered to great depths, but the soils do not seem to have correspondingly deep solums. The few latosolic soils formed from sedimentary clays are less deeply weathered and have shallower solums than do those derived from volcanic rocks.

These soils occur in moderately dissected uplands with a dendritic pattern of drainageways. Ridge crests are generally narrow, as are the valleys, and the intervening rounded slopes are relatively long. Local relief, i.e., differences in elevation within a unit area of approximately 160 acres (one-fourth square mile), are measurable in tens of feet, for the most part. In a few places local relief is measurable in one or two hundreds of feet, whereas in others it may be in feet.

Three associations are dominated by Latosols formed from volcanic rocks, whereas a fourth consists of latosolic soils derived from clays. Brief descriptive names are used to identify the major group in each association. Such names are not being suggested as proper names for great soil groups but are intended for local identification of the soils. When the name of an association is used as a subsection heading, it is followed by another name or names in parentheses. These names in parentheses identify the associations on the map of larger scale in the report on military geology of the islands (U. S. Department of the Army, 1956). The information on the larger map has been generalized in preparing the map in Figure 2.

1. Latosols from Breccias (Palau Association)

This association is dominated by Latosols that are red or reddish brown in the deeper profile. Colors are mainly of 2.5YR and 5YR hues[5] though a few soils are strong brown

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[5] Munsell color notations. The application of this system of color notations to soils is discussed in the *Soil Survey Manual* (Soil Survey Staff, 1951).

(7.5YR hue) and a very few yellowish brown (10YR hue) below the A horizon. Bauxitic Latosols, Alluvial Soils, and Lithosols or lithosolic soils are minor components of the association. With a total area of 78 square miles, this association is much the largest in the Palau Islands. It extends from one end of Babelthuap to the other, covers all of Araka-besan and Malakal, and occupies those parts of Koror and Auluptagel underlain by volcanic rocks.

Topography is largely hilly; dominant slope gradients fall between 15 and 45 per cent. Departures from the dominant topography occur on major divides, where the uplands are undulating or gently rolling, and immediately adjacent to the valleys of large streams, where slopes are commonly steep. Hilly topography, however, dominates the association.

A profile description to illustrate the major reddish Latosols of the association follows.

(a) *Setting*. This profile was described and sampled on the island of Arakabesan about 1,000 yards west of the causeway leading to Koror. The site is about 100 feet above sea level in well-dissected uplands and has a slope of 15 per cent to the east. Vegetation in the vicinity has been disturbed by fire and by cutting, though there was little cultivation in evidence.

(b) *Profile Description*.

A_1 0-12″ Dark reddish-brown (5YR 3/4) silty clay loam, dark brown (7.5YR 3/4) when dry; weak, fine and very fine granular structure; soft, very friable; many roots; few stone fragments; strongly acid.

B_{21} 12-26″ Dark red (2.5YR 3/6) silty clay, yellowish red (5YR 4/6) when dry; compound structure of moderate fine and medium subangular blocks breaking readily to moderate fine and medium

granules; slightly hard, friable, slightly plastic; roots common; few pinholes, wormholes, and stone fragments; strongly acid.

B_{22} 26-33″ Yellowish-red (5YR 4/6) silty clay, yellowish red (5YR 5/6) when dry; compound structure of moderate fine and medium angular blocks breaking readily to moderate medium and fine granules; slightly hard; friable, slightly plastic; few roots; pinholes and wormholes common; strongly acid.

B_{23} 33-39″ Comparable to B_{21} in texture, structure, and consistence but dark red (2.5YR 3/8) in color; few roots; pinholes and wormholes common; strongly acid.

C_1 39-60″ Brindled and finely variegated red, yellowish-red, pale-yellow, and light-gray (intermediate colors also present) silty clay loam; massive; soft, very friable; strongly acid.

C_2 60-102″ Similar to C_1 horizon but with lower proportions of grays in the color pattern.

C_3 102-120″ Finely variegated reddish-yellow and light-gray silty clay loam with few medium distinct mottles of weak red; massive in place but breaks out in weak coarse plates with black coatings on many faces; slightly hard, firm; strongly acid.

(c) *Additional Notes*. The identification of the B_{22} and B_{23} horizons is open to question. The B_{22} is like the adjacent ones in texture,

structure, and consistence but not in color. The differences may reflect marked banding in the original parent materials or disturbance of some kind, possibly by man. Disturbance seems probable in view of widespread occurrence of pottery fragments at some depth in Latosol profiles in the Palau Islands. Laboratory data also suggest the possibility that the present B_{23} horizon may at one time have been an A horizon, later covered by soil material of similar composition moved downslope from higher uplands.

The slope gradient at the profile site on Arakabesan falls near the lower end of the dominant range for the association as a whole. Consequently, the solum is thicker than average. It is estimated that 10 per cent of the Latosols in this association have deeper solums and that 60 per cent have slightly shallower solums, i.e., between 2 and 3 feet. The remaining 30 per cent have solum thicknesses falling between 1 and 2 feet. Regardless of variations in solum thickness the regolith is deep for all Latosols in this association, commonly ranging from 10 to 60 feet. Occasionally, thickness of the regolith may exceed 60 feet to the underlying basaltic or andesitic volcanic Breccias.

Concretionary or bauxitic Latosols, Lithosols and lithosolic soils, and Alluvial Soils comprise from 10 to 15 per cent of the association. Proportions of these three minor groups are approximately equal. The concretionary Latosols are similar to the dominant soils in the association of bauxitic Latosols from Breccias. In contrast to the Latosols, the Lithosols and lithosolic soils are formed in shallow regoliths, usually marked by rock outcrops. The Alluvial Soils occupy toe slopes and narrow valleys and are similar to those described in the subsection on Regosols, Alluvial Soils, and Organic Soils.

2. Bauxitic Latosols from Breccias (Babelthuap Association)

The dominant soils of this association are the most strongly weathered Latosols of the islands. Striking features of these soils are the large numbers of concretions on the surface and in the profile. Approximately half of the total area of this association consists of reddish, bauxitic Latosols. Most of the remainder consists of Latosols that are low or lacking in concretions, but there are also minor proportions of Lithosols or lithosolic soils and of Alluvial Soils. Much less extensive than Latosols from Breccias, this association has a total of 19 square miles, all on Babelthuap. Major areas are in the west central part of the island, though two small ones are near the south coast.

Topography is dominantly hilly. Slopes may be slightly steeper, on the average, than they are in the association of Latosols from Breccias. Local relief is commonly measurable in many tens of feet.

A profile description representative of the dominant bauxitic Latosol of the association is as follows:

(a) *Setting*. The profile was described and sampled in a former strip mine used for the extraction of bauxitic ore, approximately 1,600 yards south of Ngardmau on Babelthuap. The site has a slope of about 15 per cent to the east. Vegetation near the strip mine consists of coarse grasses and brush interspersed with almost pure stands of ferns (*Gleichenia linearis*).

(b) *Profile Description.*

A_1	0-6''	Brown (7.5YR 4/4) gravelly loam; moderate fine granular structure; soft, friable; brownish coarse and very coarse vesicular platy concretions common, few brown fine concretions; many very fine, fine, and medium roots; few small worm casts; very strongly acid.
B_2	6-18''	Red (2.5YR 4/8) silty clay; compound structure of moderate coarse subangular blocks breaking

under pressure into moderate fine and medium subangular blocks; slightly hard, friable; brown fine concretions common; few fine roots; extremely acid.

C₁ 18-28″ Variegated red (2.5YR 4/8), weak red (10R 4/3), and reddish-yellow (5YR 6/8) silty clay loam; massive; slightly hard, friable; few light-gray fine concretions, few fine roots; extremely acid.

C₂ 28-32″ Variegated weak red (10R 4/3), reddish-yellow (5YR 6/8), and strong brown (7.5YR 5/6) silty clay loam; massive; slightly hard, friable; few brownish coarse and very coarse concretions; few speckles of gray (N 5/); extremely acid.

C₃ 32-76″ Variegated weak red (10R 4/3) and strong brown (7.5YR 5/6) gritty silty clay loam, appearing mottled because of light-gray (10YR 7/1) fine to coarse concretions; yellowish-red very coarse concretions common; extremely acid.

C₄ 76-96″ Variegated weak red, strong brown, and black silty clay loam; weak coarse platy structure apparently retained from parent volcanic breccia; very strongly acid.

(c) *Additional Notes.* The concretions in the A horizon are large and tend to be roughly platy, with long axes ranging from 5 to 100 mm. and short axes from 3 to 30 mm. All seem to be vesicular, and some have shiny surfaces. Concretions are most abundant in the surface layer and in the C horizon.

The nature and distribution of concretions in the profiles of dominant Latosols in this association tend to follow certain patterns. For the most part, brown, reddish-brown, and yellowish-red concretions occur in the surface layer, though they are found at depth in some profiles. Gray and light gray concretions occur in the C horizon, especially in the upper part. Colors suggest that concretions in the deeper profile are more often low in iron oxides than those near the surface. Most concretions in the upper horizons are somewhat flattened and platy, with a few being roughly spherical. In the deeper horizons, the concretions may be platy, spherical, or assume branching cylindrical forms much like reef coral. The spherical and platy forms are most common. Total numbers of concretions are greatest in the A and C horizons, and seem to be lowest in the B horizon. Numbers of concretions decrease with increasing depth in and below the C horizon, as a rule.

Sequences and thicknesses of horizons and the degree of horizonation are not uniform among the bauxitic Latosols and related soils dominant in this association. As already indicated, these soils comprise about half of the total area of the association. Perhaps 25 per cent of the soils in this half have the horizon sequence and thicknesses as described for the one profile. Other soils either have been eroded or have failed to reach the same degree of horizon differentiation. Most of the soils have thinner A horizons than the described profile, some lack an A horizon, and others seem to have lost both A and B horizons. Some of these last-named soils have thin A horizons which seem to be in process of formation from former C horizons. Thus, about three-fourths of the bauxitic Latosols and related soils in the association have profiles somewhat like but not identical with the one described near Ngardmau. Regardless of the character of the profile, the Regolith is consistently deep, commonly exceeding 30 feet and often reaching 50 feet.

Second in extent in the association are

Latosols formed from volcanic Breccias but lacking large numbers of concretions in the profile. These soils are identical with the dominant ones in the association of Latosols from Breccias, described earlier. Some do have more concretions in the surface layer than typical, thus being intermediate in character between the bauxitic and nonbauxitic Latosols.

Lithosols or lithosolic soils and Alluvial Soils comprise 10 per cent or less of the association. The nature and distribution of these minor soils is similar in the two associations of Latosols from volcanic Breccias.

3. Latosols from Tuffs (Ngardok Association)

Although derived from different parent materials, the dominant soils of this association closely resemble the Latosols formed from volcanic Breccias, especially those low in concretions. On the whole, the soils from tuffs have thinner solums and slightly lower permeability. They have fewer concretions in the profile and seem to be less weathered than the bauxitic Latosols from Breccias. Minor components of the association are Alluvial Soils and Regosols or regosolic soils. Total area of the association is 13 square miles, which is one-fifth that of the Latosols from Breccias. Latosols from Tuffs occur only on Babelthuap, mainly in the northern half of the island.

The land surface of this soil association is highly dissected. Topography is mostly hilly to steep with local relief in many tens of feet. Ridge crests are commonly narrow but valleys are fairly broad with much fill. Occasional uplands have been dissected so as to resemble miniature Badlands, which are conspicuous though small.

A profile description to represent the Latosols from Tuffs follows.

(a) *Setting*. The profile was described and sampled south of the village of Aimeong, west central Babelthuap. The site was a 25 per cent slope to the west in uplands about 100 feet above sea level and less than 100 yards from a mangrove swamp. The vegetation at the site consisted of coarse grasses and low shrubs.

(b) *Profile Description*.

A_1	0-3″	Reddish-brown (5YR 4/4) silty clay loam; weak medium granular structure; soft, friable; many fine and medium roots, few wormholes and pinholes; strongly acid.
B	3-18″	Yellowish-red (5YR 4/8) silty clay; weak coarse and medium subangular blocky structure; slightly hard, firm, slightly plastic, slightly sticky; many fine roots; few pinholes; strongly acid.
C_1	18-42″	Bedded deposit of weathered tuffs in which the main layers are variegated weak red (10R 4/2), red (10R 4/8), pale yellow (2.5Y 7/4), and white (2.5Y 7/2) silty clay loam that is soft and friable. Intercalated layers are reddish-yellow (7.5YR 6/6) silty clay that is hard, firm, slightly sticky, and slightly plastic. The whole horizon has weak, very coarse platy structure inherited from original deposit and is strongly acid.
C	42-60″	Variegated weak red (10Y 4/2) and pale-yellow (2.5Y 7/4) silt loam with very fine white (2.5Y 8/2) specks; massive; soft, very friable; strongly acid.

Major differences among the Latosols from Tuffs are in thickness and color of solum. Approximately half of these soils have solums 1½ or more feet thick. Another fourth have solums between 1 and 1½ feet in thickness.

The remainder have solums which are less than 1 foot thick. Colors range from low chromas and values of 10R hue to rather high figures of 7.5YR hue. The bulk of the soils have colors of 2.5YR and 5YR hues. Some profiles have appreciable numbers of concretions of various sizes in and on the surface layer. Concretions may be common but not numerous. Thickness of the Regolith in which the soils are formed is generally great, commonly falling between 40 and 100 feet.

Minor components of this association, the Alluvial Soils and Regosols or regosolic soils, form 10 to 15 per cent of its total area. The Alluvial Soils are similar to those in other associations dominated by Latosols. The Regosols or regosolic soils are restricted to the steepest slopes and have about the same total area as Alluvial Soils. The Regosols or regosolic soils may have faint A horizons or may consist entirely of weathered Tuffs.

4. Latosolic Soils from Clays (Ngatpang Association and Tabagaten Association)

Two soil groups are the main components of this association, all of which are derived from sedimentary clay beds. The more extensive group consists of Red-Yellow Podzolic soils which approach Planosols in fine texture and low permeability of the B horizon. They resemble the Colbert series formed from argillaceous limestones in the southeastern United States. The B horizons are mainly yellowish-brown (10YR hue) silty clays. The second major group in the association consists of yellowish-red to red soils which seem to be intermediate in character between Latosols and Red-Yellow Podzolic soils. They have some of the properties of each. They may be more nearly related to the Davidson, Decatur, and similar series than to typical Latosols or Red-Yellow Podzolic soils. All gradations in profile exist between the yellowish-brown and red components of this association.

Minor components of the association are Low Humic-Gley soils, Alluvial Soils, and Regosols, which collectively comprise about 20 per cent of its total area. Low Humic-Gley soils occur in smooth uplands and on the lower parts of long slopes. Alluvial Soils are found along drainageways. The Regosols occupy the rare steep slopes.

Restricted in its occurrence on Babelthuap, this association has a total area of about 5 square miles. The main bodies are in the west central part of the island, with a few small ones near the southern end.

Topography is dominantly undulating to rolling, in contrast to the hilliness of the Latosols from Breccias and Tuffs. Slopes are long and gentle. Local relief is measurable in feet as a rule though it may reach tens of feet in a few places. Latosolic soils from clays comprise the smoothest uplands on Babelthuap.

5. Chemical and Mineralogical Data on Profiles

Certain laboratory analyses have been made on samples of the major horizons of several profiles from the Palau Islands. Data obtained will be given in full in a later publication, but a few are given here to complement the morphological observations. Table 1 gives data for exchangeable cations, pH, exchange capacity, base saturation, and organic matter for three profiles which represent the dominant Latosols of the islands. Table 2 gives data on chemical and mineralogical composition on a section sampled for the study of bauxite ore in an area of bauxitic Latosols.

The laboratory analyses reported in Table 1 were made in the Department of Soils and Agricultural Chemistry, University of Hawaii, and in the Soil Survey Laboratories, SCS, U. S. Department of Agriculture. Methods used at the University of Hawaii are described by Piper (1944), whereas those used in the Soil Survey Laboratories are described in U. S. Department of Agriculture Circular 757 (Peech et al., 1947).

Data given in Table 2 are from the laboratories of the U. S. Geological Survey. Standard methods for chemical analysis were used

TABLE 1
EXCHANGEABLE CALCIUM AND MAGNESIUM, pH, EXCHANGE CAPACITY, BASE SATURATION, AND ORGANIC MATTER IN THREE LATOSOL PROFILES

HORIZON	DEPTH	pH	CATION EXCH. CAPACITY	EXCHANGEABLE CALCIUM	EXCHANGEABLE MAGNESIUM	BASE SATURATION	ORGANIC MATTER
	Inches		m.e./100 g	m.e./100 g	m.e./100 g	Per cent	Per cent
LATOSOL FROM BRECCIA*							
A1.........	0–12	5.6	22.4	8.3	1.8	45	5.20
B21........	12–26	5.6	15.3	6.2	0.8	46	2.35
B22.......	26–33	5.8	16.7	6.6	0.7	44	2.45
B23.......	33–39	6.2	20.3	7.8	0.5	41	1.44
C11.......·.	39–60	6.2	13.9	7.6	0.5	58	0.50
C12.......	60–88	6.6	15.8	8.8	0.7	60	0.37
BAUXITIC LATOSOL FROM BRECCIA*							
A1.........	0–6	5.0	12.0	0.4	0.4	6	4.79
B2.........	6–18	5.0	8.3	0.1	0.4	7	2.38
C1.........	18–28	5.2	10.1	0.3	0.5	4	0.98
C2.........	28–34	5.2	10.2	0.3	0.6	10	0.85
C3.........	34–76	5.2	14.3	0.2	0.3	4	0.64
LATOSOL FROM TUFFS†							
A.........	0–3		36.7	7.1	5.7	37	
B.........	3–18		31.0	12.2	2.8	50	
C1.........	18–42		31.5	19.6	1.8	69	
C2.........	42–60		30.7	17.6	1.7	64	

* Analyses through courtesy of Dr. G. D. Sherman, Chairman, Department of Soils and Agricultural Chemistry, University of Hawaii.

† Analyses by E. M. Roller, Soil Survey Laboratories, Soil Conservation Service, U. S. Dept. of Agriculture.

in determining composition of samples given in Table 2. The quantities of gibbsite and of silicate clay minerals were estimated by Goldich from differential thermal analyses and the chemical analyses. Hematite and other minerals were obtained by difference.

6. Comparisons of Soils in Palau Islands, Hawaii, and Puerto Rico

The Latosols in the Palaus have low degrees of horizonation, diffuse horizon boundaries, and common to numerous pinholes in the profile. Morphologically, they are comparable to Latosols observed by Simonson in Hawaii, Puerto Rico, Ceylon, and Brazil. There are differences, however, among the

Latosols in the Palaus as there are elsewhere. The Latosols low or lacking in concretions seem to be much less strongly weathered than are the bauxitic Latosols high in concretions. This inference is based on differences in morphology and on laboratory data given in Tables 1 and 2.

The Latosols low or lacking in concretions have A horizons that are easily recognized because they are darker and more friable than the B and C horizons. The B horizons are set apart because they are more plastic and less friable than the C horizons. Differences in plasticity are slight as indicated by dominant ranges in plastic index values (Casagrande, 1932) of 6 to 9 for the A horizons, 21 to 31 for

TABLE 2

COMPOSITION OF LAYERS FROM A DEEP SECTION THROUGH A BAUXITIC LATOSOL
FROM BRECCIA NEAR NGARDMAU, BABELTHUAP*

DEPTH	SiO_2	Al_2O_3	Fe_2O_3	TiO_2	LOSS ON IGNITION	GIBBSITE	SILICATE CLAY MINERALS	HEMATITE AND OTHER MINERALS
Inches	Per cent	Per cent	Per cent	Per cent	Per cent	Per cent	Per cent	Per cent
0–20................	0.98	44.12	25.55	1.38	26.14	66	2	32
20–28................	1.64	34.83	37.56	1.68	21.76	51	4	45
28–120..............	7.63	37.33	29.85	1.70	21.22	47	17	36
120–180.............	19.40	35.21	24.62	1.42	18.75	29	42	29

* Sampled by S. S. Goldich; hole 17, Taihei Area. Chemical analysis by Marie L. Lindberg, U. S. Geological Survey.

the B horizons, and 6 to 18 for the C horizons. The C_1 horizon of the Latosol profile described on Arakabesan has a plastic index of 31, which is in the common range for B horizons.

Morphologically, the dominant Latosols in the Palaus are like the Humic Latosols in Hawaii, described by Cline (Cline *et al.*, 1939). The profiles from breccias and tuffs are much like the Humic Latosols in the character, sequence, and thickness of horizons. Both profiles in the Palaus, however, are lower in organic matter than Humic Latosols in Hawaii, being more like the Low Humic Latosols in this feature. The profile from tuffs has exchange capacities ranging from 31 to 37 milliequivalents per 100 grams which falls within the common range of 30 to 40 milliequivalents for Humic Latosols in Hawaii. On the other hand, the profile from breccia has exchange capacities ranging from 14 to 22 milliequivalents per 100 grams which parallels the range of 15 to 30 milliequivalents for Low Humic Latosols. Ratios of exchangeable calcium to magnesium are much higher in the two profiles from the Palaus than they are in the Humic Latosols or Low Humic Latosols of Hawaii. All in all, the less weathered Latosols of the Palau Islands seem marginal between the Low Humic Latosol and Humic Latosol groups recognized in the Hawaiian Islands.

The Latosols in the Palaus also resemble those in Hawaii in low plasticity and stickiness despite high clay contents. Some Low Humic Latosols in Hawaii are 80 per cent clay but feel as though they were silty clay loams when worked between the fingers. Field textures of Latosols in the Palaus seem marginal between silty clay loam and silt loam in the A_1 horizons and between silty clay and silty clay loam in the B horizons. There is little reason to believe that the Latosols of the Palaus are lower in clay than those in Hawaii.

Latosols, though high in clay, commonly have low shrinkage values upon drying and show little or no expansion upon wetting. This behavior has been correlated with high liquid limit and low plastic index values. The liquid limits for Latosols in the Palau Islands mostly range from 56 to 82. Lower values were found in the bauxitic Latosol, which had liquid limits of 39 in the A_1 and 45 in the lower C horizons. The plastic index ranges from 6 to 31, as was indicated in an earlier paragraph. Within the continental United States liquid limit and plastic index values of similar magnitude are found in the Davidson series (Fruhauf, 1946) and similar soils, which have been classified in the Reddish-Brown Lateritic group (Simonson, 1949). Although similar to Latosols in a number of ways, the Davidson profile has a much more distinct and far less friable B horizon. Field descriptions of the Latosols in the Palaus as well as the liquid limit and plastic index values sug-

gest that these soils lean somewhat in their characteristics toward the Davidson series. Hence, they seem to be intermediate between modal profiles for the Latosol group and the Reddish-Brown Lateritic soils.

The morphology and composition of the bauxitic Latosols in the Palau Islands indicate that they are more strongly weathered than the Humic Latosols and more nearly comparable in this respect to the Humic Ferruginous Latosols of Hawaii. Sesquioxides have been concentrated to a high degree, partly in the form of concretions, in the bauxitic profiles (Table 2). Compared to the Haiku and Naiwa series in Hawaii (Cline *et al.*, 1939), the bauxitic profile is much lower in SiO_2 and TiO_2, somewhat lower in Fe_2O_3, and much higher in Al_2O_3. It is comparable in contents of SiO_2 and TiO_2, lower in Fe_2O_3, and higher in Al_2O_3 than the profiles of Nipe clay described by Marbut (1930). Thus the concentration of sesquioxides, considering both aluminum and iron, is comparable in the bauxitic Latosol to that of Humic Ferruginous Latosols of Hawaii and to the Laterite soils of Cuba and Puerto Rico. The chemical and mineralogical composition of the bauxitic profiles as indicated in Tables 1 and 2 suggests that it is one of the end products of soil formation in the humid tropics.

The Latosols of the Palau Islands clearly represent two subdivisions of the broad group or suborder. The bauxitic soils are examples of a strongly weathered group similar in many ways to the Nipe clay of Cuba and Puerto Rico and to the Humic Ferruginous Latosols of Hawaii. On the other hand, the profiles low or lacking in concretions in the Palau Islands resemble the Humic Latosols of Hawaii in some ways and the Low Humic Latosols in others. It may be that they should be considered comparable to Humic Latosols in the drier part of their climatic range. Dominant Latosols of the Palau Islands also seem to have a few properties in common with the Reddish-Brown Lateritic group of the southeastern United States.

Regosols, Alluvial Soils, and Organic Soils

These soils comprise about 6 per cent of the total land area of the Palaus but produce most of the food in the present agriculture. The one Regosol is a soil type widespread on Pacific islands, known as Shioya sand. The Alluvial Soils are moderately fine-textured and predominantly poorly drained, though they have a wide range in drainage conditions. Organic Soils consist of peats and mucks. The Alluvial Soils are slightly more extensive than either Shioya sand or the Organic Soils.

1. Shioya Sand

This soil type occupies raised beaches or low coastal terraces that are above wave action, principally in north Peleliu and at the north and south ends of Angaur. Additional areas too small to be shown in Figure 2 occur along the northeastern coast of Babelthuap and along the shores of Peleliu. Total area of Shioya sand in the islands is 2.7 square miles.

The profile of Shioya sand consists of a thin (2–3 inches) gray (2.5Y 5/1) or grayish brown (10YR 5/2) A_1 horizon over a light gray (2.5Y 7/2) C horizon. The whole profile consists of sand or fine sand, which may be replaced by gravel at depths of 2 to 4 feet. In most places, some coral fragments occur on the surface and throughout the profile. Consisting largely of coralline limestone fragments, Shioya sand is strongly calcareous.

Much of the total area of Shioya sand has been planted to coconut palms, for which the soil is well suited. Minor crops that seem to grow well are lemons, bananas, papayas, and breadfruit.

2. Alluvial Soils

These soils occur along most streams and along many of the upland drainageways in the Palau Islands. Only the areas along the lower courses of principal streams can be shown, however, in Figure 2. The soils are all slightly acid in reaction, and the dominant ones are poorly drained. Less extensive are the well-drained soils and those intermediate in

drainage. Total area of this association is slightly more than 4 square miles.

The dominant poorly-drained soils show the effects of a water table at or near the surface an important part of each year. A typical profile has a surface layer of brown (7.5YR 4/4) silty clay loam about 9 inches thick underlain by gray (5Y 5/1) or olive-gray (5Y 4/2) silty clay mottled with brownish yellow (10YR 6/8). Somewhere between 2½ and 4 feet this gives way to dark-gray, nearly impermeable clay free of mottles.

Well-drained soils in this association are commonly of similar texture but have brown surface layers grading downward into red, reddish brown, yellowish red, or yellowish brown. Mottled patterns and colors of 5Y hue are lacking in the well-drained soils. Soils with drainage intermediate between the well-drained and poorly drained ones are also intermediate in their morphology.

The Alluvial Soils are adapted to most crops that can be grown in the Palau Islands. In spite of the suitability of the soils for cultivation, however, very little of this association was being tilled in 1948. Most areas were idle, generally supporting tall coarse grasses which were replaced locally by poor forest. Taro was being grown on some patches of wet Alluvial Soils near villages. Other crops that seem to grow well on the Alluvial Soils are cassava, bananas, coconuts, and pineapples.

3. Muck and Peat

These organic soils are of major importance to present food production, despite their small total area. They occur as scattered individual bodies, mostly along the northeast coast of Babelthuap and on the islands of Angaur and Peleliu. Some bodies are too small to be shown in Figure 2. The total area of organic soils is slightly less than 3 square miles.

Muck consists of black, neutral to mildly alkaline, highly decomposed organic matter mixed with some mineral matter. Thickness of the muck commonly ranges from 2 to 3½ feet although it may be slightly less than 1 foot thick in places. The muck is generally underlain by gray silt, gray clay, or coral sand. On Angaur, all of the muck is underlain by phosphate ore in the form of pellets. Approximately 90 per cent of the total area of organic soils consists of muck.

Peat is less decayed than muck and is also commonly lower in mineral matter. Plant structures in the peat can be readily identified. The deposits range from 1 to 3½ feet in thickness over limestone or phosphate ore. The areas of peat are approximately 10 per cent of the total of Organic Soils.

The Organic Soils are especially valuable in the Palau Islands because of their suitability for taro production. They produce high yields of the crop, which is a major item in the diet of the people.

Lithosols, Stony Land, Rock Land, and Mangrove Swamp

This group comprises one soil association and three miscellaneous land types. Collectively, the group has a total area of 49 square miles, ranking second to the Latosols from Breccias. Despite their large extent, however, the Lithosols and miscellaneous land types have little usefulness to agriculture.

1. Lithosols from Volcanic Rocks

The main features of this association are the shallowness of soils, common occurrence of rock outcrops, and steep topography. Usually 6 to 15 inches deep over hard rock, the soil is dark, slightly acid, and commonly marked by a faint and thin A_1 horizon. Rock fragments are common on the surface and throughout the profile. Massive rock outcrops occur along ridge crests. The association has steep to hilly topography and is covered by forest or savanna. The steepest areas are mostly in forest, whereas the remainder is covered by coarse grasses and low shrubs with scattered pandanus trees. Restricted to Babelthuap and small nearby islands not

shown in Figure 2, this association has a total area of 7 square miles.

2. Smooth Stony Land

Smooth stony land is largely covered by limestone fragments or rubble, among which are small quantities of fine earth, usually phosphatic. For the most part, large limestone fragments are numerous enough on the surface so that a person can easily step from stone to stone. Pockets of soil material are commonly tiny but a few are as big as 1/100th of an acre. The soil material is dark brown, friable, silt loam to loamy coarse sand and may reach depths of 10 inches in some pockets. As the name of the land type suggests, smooth stony land is nearly level or very gently sloping. It forms important parts of Angaur and Peleliu and has a total area of 2½ square miles.

Most areas of smooth stony land are covered by brush and small trees. Small clearings, usually a fraction of an acre in size, are made here and there in the forest for the planting of cassava, sweet potatoes, bananas, and papayas. These may be planted separately or in mixtures, more often the latter. Individual clearings are usually abandoned to the forest again after a few crops have been produced.

3. Limestone Outcrops

This form of rock land, as its name suggests, comprises exposures of coralline limestone and rubble with little or no fine earth. The surface of the limestone is commonly pitted and pinnacled. Some soil material is present in small pockets and in crevices, generally in handfuls. Present vegetation consists of small trees and shrubs. Limestone outcrop forms the islands of Urukthapel, Eil Malk, and Ngergoe (all of which lie between Koror and Peleliu and are not shown in Figure 2); parts of Anguar, Auluptagel, Koror, and Peleliu; and the southern tip of Babelthuap. It also forms a number of small unnamed islands between Koror and Peleliu. This land type has a total area of 24 square miles, none of which is inhabited.

4. Mangrove Swamp

This miscellaneous land type comprises wooded coastal areas that are periodically flooded by salt or brackish water because of tides. The mangrove swamps occur along the coasts, on deltas, in embayments, and along the lower reaches of the streams. The main areas border the coast of Babelthuap and the eastern coast of Peleliu. Total area of mangrove swamp in the Palau Islands is slightly more than 14 square miles.

AGRICULTURE

Agricultural production in the Palau Islands in 1948 was of a subsistence type. The crops being grown were used as food for the families producing them. The main food crops were taro, cassava, and sweet potatoes. Production of these crops was by hand tillage, a clear index to the prevailing level of agricultural technology.

Crops

Taro (*Colocasia esculenta*), which yields an edible tuber, is produced mainly on Organic Soils and poorly-drained Alluvial Soils in the Palaus. It is also grown to a limited extent on Latosols, preferably on lower slopes where some seepage can be expected. Commonly grown with taro but on the outer margin of the paddies is a coarser plant (*Cyrtosperma chamissonis*) which produces a large tuber eaten when the taro crop fails. Several large "elephant ear" varieties, identified by Fosberg[6] as *Xanthosoma violacea* and *Alocasia macrorrhiza*, are grown occasionally on soils of the uplands. Like the *Cyrtosperma* in the paddies, these are also eaten only during severe food shortages.

The second crop of importance is cassava (*Manihot utilissima*), called "tapico" by the Palauans. It commonly supplements and may replace taro in the diet. The crop was introduced during German ownership of the is-

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[6] Personal communication, April 9, 1951.

lands. Improved varieties with higher starch contents were brought in by the Japanese who raised cassava for export. The crop grows best during the driest season of the year, when fungus diseases are the least active. It is grown mainly on the Latosols but to some extent on Alluvial Soils.

Third in importance among food crops are sweet potatoes, which were introduced by the Spaniards. Sweet potatoes are produced by the same methods as cassava. They are grown on the Latosols, some Alluvial Soils, and Shioya sand.

Minor crops are coconuts, sugar cane, Tahitian chestnuts, breadfruit, jakfruit, pineapples, oranges, mangoes, papayas, sauersop, and pandanus. Coconut plantations were relatively important at one time but the invasion of the rhinoceros beetle has reduced production to very low levels and forced abandonment of most groves. Sugar cane, pineapples, and papayas are grown as scattered plants in a patch of cassava, sweet potatoes, or both. Orange and mango trees producing food are commonly lone plants in or near the villages, whereas chestnuts, breadfruit, jakfruit, sauersop, and pandanus grow wild in the savannas and forests.

Methods

Shifting cultivation is the general practice in the production of food crops on the Latosols of the Palau Islands. Most areas of Latosols readily accessible to villages are now in savanna vegetation. Burning of the grass is therefore the first step in clearing a garden patch. A few areas of Latosols as well as most of the smooth stony land is in forest or brush. Clearing of a garden then requires the cutting of saplings, vines, and brush, usually done with a large knife or machete. After the savanna is burned or the forest cut, the soil is stirred with a simple hoe and crops are planted.

All tillage, planting, and harvesting in the Palau Islands are done by hand. No draft animals were on the islands in 1948 nor had they

been used in the past. Cultivation of the soil is by means of a four-pronged hoe introduced by the Japanese. Tillage consists of stirring of the soil to shallow depths. Subsequently, slips or seeds are planted. Vegetative reproduction by means of slips is the more common practice.

Garden patches on Latosols and some on Alluvial Soils and smooth stony land are usually planted to cassava or sweet potatoes. Some gardens may have both crops growing at the same time, plus scattered individual plants of other crop species. A single garden may be used for cassava or sweet potatoes exclusively, or the two may be alternated. After the plants become ripe they are harvested a few at a time, as needed by the family. The patch is replanted with cassava or sweet potatoes after all of one crop has been harvested. This process is then repeated until yields in that one garden patch begin to drop. Once the yields have fallen, the patch is abandoned and a new one is cleared either by fire or knife. The whole process is then repeated once more in the new clearing.

Continuous growing of taro is common practice on the Organic Soils and the poorly drained Alluvial Soils. The planting, weeding, and harvesting of taro are the responsibility of the women in the families, who also own the taro paddies. The paddies used by a single family are divided into a number of segments and planted so that one segment is always ready for harvest. Thus, the plants in different segments of one paddy may be in all stages of growth from slips that have just been placed into the soil to ripe plants awaiting harvest. After all of the plants in a given segment have been harvested, that segment is again replanted while harvest begins in another part of the paddy. Taro paddies commonly receive more attention than do upland gardens because of their greater importance in food production.

Efforts are made by the Palauans to incorporate decayed leaves and grass as well as wood ashes into the soils, especially in taro

paddies. Commercial fertilizers, insecticides, and the like, have not been available in the Palau Islands. Methods used by the Palauans to maintain and improve their soils as well as methods of tillage, planting, and harvesting are all common elements of a simple agricultural technology.

Potentialities

Improvements in agricultural technology would permit increased food production from the soils of the Palau Islands. Some improvements are possible within existing patterns of operation. For example, better crop varieties, commercial fertilizers and insecticides, and simple machinery such as hand cultivators could be used in the present agriculture. Certain shifts are thus possible without major changes in the agricultural arts. Such shifts would mean appreciable increases in food production, without realization of the full potentials of the soils.

To achieve full potential production from soils of the Palaus, major changes from the present agricultural technology would be required. What the potential may be can be inferred from current yields on Humic Latosols and Low Humic Latosols of Hawaii, soils which are comparable to those of the Palau Islands. Yields of 8 to 10 tons of sugar per acre are common on the Latosols of Hawaii (Cline *et al.*, 1939), where soil management includes heavy fertilization, irrigation, mechanization, and many more of the management elements available to agriculture in a modern industrial society. The findings of modern science and the products of modern industry are widely used for crop production on Latosols in Hawaii. Thus, the level of agricultural technology is markedly different from the one prevailing in the Palau Islands.

Experience in soil use and management does not seem directly transferable from Hawaii to the Palaus, though major soils in the two island groups are the same. The total land area and the topography of the Palaus impose certain limitations on agricultural production even with the best technology available. The small total area of the Palaus in itself restricts opportunities for the large scale agriculture in which sugar cane, cacao, and similar crops are commonly produced. Furthermore, the major soil associations of the Palau Islands are dominantly hilly to steep. Individual areas with level, undulating, or rolling topography are small. Proportions of the major soil associations with topography favorable for mechanization are therefore small. As a consequence, full use of the tools of soil management available in a modern industrial society does not promise to become feasible in the Palaus. Something less than full use of those tools is more likely to be appropriate. Possibilities for commercial agricultural production seem limited, all in all, but there is opportunity for greater food production through improvements in soil use and management.

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Pacific Area Distribution of Fresh-Water and Marine Cercarial Dermatitis[1]

GEORGE W. T. C. CHU[2]

CERCARIAL DERMATITIS, a form of "swimmer's itch," is a skin infection caused by the penetration of schistosome cercariae. The disease is also known as schistosome dermatitis. The clinical symptoms start with an itching sensation, which is followed by the development of a rash or petechiae, and in many hypersensitive persons papular eruptions appear together with intensive itching and edema. It is a self-limiting ailment if no further infection is contracted. It is neither a communicable disease nor a fatal one, but the discomfort and the pathology of the infection contribute to its importance in the field of public health and veterinary medicine.

The disease is of geographical interest because it is a "Disease of the Place," as explained by Jarcho and Van Burkalow (1952). Normally the adults of the dermatitis-producing schistosomes are blood parasites of birds, or, in some instances, of mammals. The life cycle begins with the hatching of the eggs which are present in the droppings of infected animals. Suitable species of snails become infected upon contact with the miracidia hatched from the eggs, the snails serving as the intermediate host. After a proper incubation period in the snail, the infectious schistosome cercariae are issued into the surrounding water. Upon exposure to these cercariae, the bird or mammalian definitive hosts are infected and the parasites mature in the vascular system of the hosts. The life cycle is completed when the adult worms produce eggs. Humans contracting the cercarial dermatitis are only the result of accidental intrusion into the life cycle of these interesting parasites.

Therefore in any geographical area, the conditions responsible for the occurrence of cercarial dermatitis are: (1) the presence of birds infected with dermatitis-producing schistosomes, (2) the presence of the snail intermediate hosts with habits conducive to the acquisition of the disease, (3) ecological conditions favorable for the survival of both the hosts and the parasites, and (4) the presence of human beings engaged in an activity which exposes them to the infection. In many parts of the world these four basic factors are present, and, as a result, the distribution of cercarial dermatitis is worldwide (Cort, 1950; Kuntz, 1955).

In the Pacific area, the disease occurs at various locations on the west coast of the North American continent extending north to Alaska. It has been reported from Japan, the Federation of Malaya, Australia, and as far south as New Zealand. The Hawaiian Islands chain is not entirely free from the presence of this disease. The following report is an attempt to summarize from the literature[3] the important facts concerning the vectors and reservoir hosts of cercarial dermatitis and to emphasize the distribution and transmission of both fresh-water and marine schistosomes in various parts of the Pacific.

ACKNOWLEDGMENTS

[3] The survey of literature on cercarial dermatitis was concluded in July, 1957.

quiries on cercarial dermatitis: Dr. W. R. Giedt, chief of Division of Epidemiology and Laboratories, Department of Health, Washington; Richard F. Peters, chief of Bureau of Vector Control, and Benjamin Keh, assistant vector control specialist, Bureau of Vector Control, Department of Public Health, California; Ralph B. Williams, director of Division of Public Health Laboratories, Alaskan Department of Health; Curtiss M. Everets, Jr., director of Division of Sanitation and Engineering, Oregon State Board of Health; Dr. W. E. Martin, professor of zoology and chairman, Department of Biology, University of Southern California; and Dr. H. F. Hsu, research assistant professor, Department of Hygiene and Preventive Medicine, State University of Iowa. Special thanks are offered Dr. J. R. Audy, of the Institute for Medical Research, Kuala Lumpur, Federation of Malaya, for suggesting the preparation of this report and for the invitation to participate in this symposium, General Ecology of Man, Animal Reservoirs, and Vectors in Relation to Disease, at the Ninth Pacific Science Congress.

A. FRESH-WATER CERCARIAL DERMATITIS

1. *United States and Canadian Pacific Coasts*

The etiology of swimmer's itch was first elucidated by Cort in Michigan, U. S. A., in 1928. Since that time, it has been recognized that "nonhuman" species of schistosomes are responsible for many cases of swimmer's itch. In the United States and Canada, Jarcho and Van Burkalow (1952) indicated recently in their report that "the states most strongly affected are Michigan, Wisconsin, and Minnesota. A few clinical cases (cercariae not identified) have been reported from the neighboring states of Indiana, Illinois, Iowa, Nebraska, and North and South Dakota. In Canada the major areas are in Ontario, east of Georgian Bay; in Manitoba, in and near Lake Winnipeg; in Saskatchewan; and in Alberta." Other areas mentioned in the text include: British Columbia, Washington, Oregon, Quebec, New York, Maine, Nevada,

Oklahoma, Alabama, Tennessee, and Florida. The disease is common in lakes and swamps along the flyways of migratory water fowls.

Recent data, together with previous reports relative to the following Pacific states, are given as follows:

a. *Washington.* Miller (1925, 1927) was first to describe the presence of schistosome cercariae in the northwestern United States. *Cercaria elvae* from *Lymnaea stagnalis* Linn. and *Cercaria tuckerensis* from *Planorbis* spp. were obtained from Trout Lake, San Juan Sound, Washington. Swimmer's itch in the Seattle area was shown by Hunter, Shillam, Trott, and Howell (1949) to be caused by two agents: (1) the cercariae of *Trichobilharzia ocellata* (La Valette) (= *C. elvae*) from *Stagnicola palustris nutaliana*, and (2) *Cercaria physellae* of *T. physellae* (Talbot) from *Physella propinqua* (Tryon). The former species of snail was found associated with reeds and other aquatic vegetation growing in the gravel and mud bottom of the lake. It was thought that the cercariae from infected snails were carried to shore by currents created by the wind blowing towards the beaches. A similar situation was known to have existed in Douglas Lake, Michigan (Cort, 1936).

The definitive hosts for these parasites in Washington have not been described, but, according to McMullen and Beaver (1945), *C. physellae*, whose definitive host was reported to be the blue-winged teal, *Querquedula discors* (Linn.), was also infective to pigeons, mallards, and canaries; however, a Caspian tern, chickens, domestic ducklings, and gulls could not be infected. The blue-winged teal is also the definitive host of *T. ocellata* (= *T. Kossarewi*), but McMullen and Beaver showed that canaries, domestic ducklings, mallards, and pigeons could be the experimental hosts. (Chicks and a tern were resistant.) Recently Farr and Blankemeyer (1956) described a new species of schistosome, *Trichobilharzia brantae*, whose definitive host was a Canada goose (*Branta canadensis* L.) from the Turnbull National Wildlife Refuge, Washington.

Macy (1952) demonstrated that *C. elvae* from *Lymnaea stagnalis* was the causative agent for dermatitis cases at Cascade Lake, Orcas Island. Macy (1955) further reported that dermatitis cases were found at a lake south of Tacoma, Washington, and from Lake Chelan and Goose Lake, Okanogan County, in eastern Washington. In spite of the fact that a large number of lakes in the state of Washington might have harbored schistosome-infected snails, Dr. W. R. Giedt, chief of Division of Epidemiology and Laboratories of the Department of Health, received only ten reports of cases in 1955 and ten during 1956 (personal communication, 1957). Since swimmer's itch is not a reportable disease, these statistics are probably incomplete. However, the preventive measures advocated by the health officers of Washington with regard to control and avoidance of the infection must have been successful, as is indicated by the low incidence of infections.

b. *Oregon.* Macy (1955) investigated schistosome dermatitis cases in the Blue Lake area near Troutdale, Oregon. The causative agent, *C. oregonensis* from *Physa ampularia*, was a schistosome species originally described by Macfarlane and Macy (1946). It is interesting to note that these infected snails occurred most abundantly on dead or decaying vegetation in lakes, ponds, and marshes. They laid their eggs in late summer and the next generation of snails matured enough to lay their eggs during the early spring. Snails infected during late summer could carry the schistosome through the winter; thus in the following spring and summer, infected snails of both the old and new generations might produce cercariae for a longer time and therefore possibly might cause a higher level of infection in humans.

c. *California.* Simmons, Martin, and Wagner (1951) reported that the first case of freshwater cercarial dermatitis in California was derived from an artificial lake at Alendra Park in Los Angeles County. Schistosome cercariae of three different types were obtained from *Physa osculans* (Haldeman) found in this lake. The taxonomic consideration of these cercariae is currently delayed because of the efficient control of the intermediate hosts by health officers (personal communication from Dr. W. E. Martin, 1957). Walker (1954) investigated a suspected outbreak of schistosome dermatitis at Twain Harte Lake, Tuolumne County, and found bifurcated cercariae coming from a mixture of *Physella* and *Lymnaea* snails. Taxonomic determinations of the schistosomes involved in these dermatitis cases are yet to be announced. Keh and Grodhaus (1957) reported swimmer's itch at a duck club in Yuba County. Cercariae of the "*ocellata*" group were obtained from *Physa* snails and later proven by experimental infection to belong to the *Trichobilharzia* group of bird schistosomes. As yet, there is no report of schistosome infected snails or cases of cercarial dermatitis in northern California.

d. *Canada.* As indicated previously, migratory water fowls such as the blue-winged teals are known to be the definitive hosts of dermatitis-producing schistosomes. Because of the many glaciated lakes and swamps which act as bird refuges, cercarial dermatitis in Canada is known to occur in many areas. Along the Pacific coast of Canada, only two species of dermatitis-producing schistosome cercariae have been reported. These cercariae were believed to be the agents responsible for a severe outbreak in 1950 at Cultus Lake, B. C. Edwards and Jansch (1955) described these two species as *Cercaria adamsi* and *C. columbiensis*, which have *Physa coniformis* Tryon as the intermediate host. The adult forms of *C. adamsi* are now designated as *Trichobilharzia adamsi* Edwards and Jansch, 1955. The definitive hosts for *C. adamsi* were believed to be wild water fowl because domestic ducks could be infected experimentally. The authors suggested that the close resemblance of *C. columbiensis* to the cercariae of *Gigantobilharzia huronensis* Najim would indicate that the pas-

seriform birds might be the natural definitive hosts for *C. columbiensis*. Goldfinches and cardinals are known to be the hosts for *G. huronensis*.

2. *Alaska*

Students interested in cercarial dermatitis have long suspected that the disease may be present in Alaska because this region is the home of many migratory water fowls (Gabrielson, 1952). Harkema (1953, 1954, 1955, 1957) reported in a series of papers that swimmer's itch occurred in the Fairbanks and Yukon Flat areas in the Alaskan interior. He made a study of the life history of one of the two schistosome cercariae obtained from infected snails in this area. A total of 80 bodies of water was investigated during the summers of 1952 and 1953, and 20 of these 80 harbored infected snails of the species *Lymnaea palustris*, *L. stagnalis*, and *L. auricularia*. The incidence of the infection in snails seemed to vary according to location and time of the year. Additional localities having infected snails were reported in 1957.

There were no extensive human infections derived from avian schistosomes in Alaska. Some cercarial dermatitis cases were observed in the Fairbanks area in the vicinity of Fort Yukon. Harkema (1957) used cercariae from the naturally infected *Lymnaea stagnalis* for experimental infections of ducklings, and the adult worm was identified as *Trichobilharzia alaskensis* Harkema, McKeever, and Becker. The other type of schistosome cercaria remains unidentified. However, two naturally infected baldpate ducks harbored adult schistosomes belonging to the genus *Trichobilharzia*. So far there has not been an extensive study of the bird definitive hosts for schistosomes in Alaska.

Gabrielson (1952), in discussing Alaskan waterfowls and their management, stated that "Alaska has breeding populations of the Whistling Swan, Emperor Goose, White-cheeked Goose, Lesser Canada Goose, Cackling Goose, White-fronted Goose, and Black Brant. It also provides suitable nesting habitats for impressive numbers of Pintails, Mallards, Green-winged Teals, Baldpates, and Shovelers, among shallow water ducks." He thinks that the Yukon delta is not only the most important breeding area in Alaska, but one of the great waterfowl production units of the continent. The green-winged teals, pintails, and baldpates, which have an extensive continental breeding range, are less affected by man-made changes in Alaskan topography than are the other species of waterfowls. Therefore in the future, the baldpates, green-winged teals, and pintails are more likely to be implicated as reservoir hosts for the distribution of avian schistosomes.

3. *Mexico and El Salvador*

Possible fresh-water cercarial dermatitis from Lake Texcoco near Mexico City was reported by Cort (1950), but so far is unconfirmed. As far as this reviewer is aware, the only cases of swimmer's itch south of Mexico along the Pacific were those contracted from Lake Coatepeque, El Salvador, and reported by Reyes in 1944. According to Cort's account of the investigation by Reyes, the exact etiological agent was not identified. Jarcho and Van Burkalow (1952) reported that a blue-winged teal captured in this area had migrated from Douglas Lake, Michigan—the area where Professor W. W. Cort first found the cause of swimmer's itch. These blue-winged teals, according to these authors, migrate along the Mississippi River and the Atlantic coast flyways. The wintering grounds involved a large geographical area ranging from southern Florida, Texas, California, through Central America to parts of the northern South American continent, while the breeding grounds extend from the Great Lakes region westward to the Rockies and as far north as northwestern Canada.

Gabrielson (1952) showed that certain species of migratory fowls did migrate as far south as Mexico and that they could be recovered in British Columbia and the states of

Washington, Oregon, and California. Thus it is no surprise that swimmer's itch along the Pacific coast has been reported from Alaska to El Salvador.

4. *Japan*

On the western side of the Pacific Ocean, the Japanese have recognised for over 50 years the existence of a dermatitis of unknown etiology which occurred among farmers inhabiting land near Lake Shinji, Shimane Prefecture. The dermatitis is called "koganbyo" or "lakeside disease" (Hunter, Ritchie, and Tanabe, 1951).

These authors reported that Tanabe in 1947 was able to produce experimental dermatitis using the furcocercous cercariae from a species of snail now known as *Polypylis hemisphaerula* Benson. This observation was confirmed and subsequently the definitive hosts were determined. They are the large starling (*Spodiopsar cineraceus* Tamminck), the sparrow (*Passer montanus saturatus* Stejnerger), and the wagtail (*Motacilla* (*Motacilla*) *grandis* Sharpe). The adult of this species of schistosome is designated as *Gigantobilharzia sturniae* Tanabe, 1948.

The snail intermediate hosts (with 3–10 per cent infections) were commonly found on submerged vegetation or mud of rice fields and irrigation canals. Dermatitis began in mid-May and reached a peak about mid-July to mid-August, and the degree and intensity of the infection appeared to be correlated with the aquatic activity of the rice farmers. Surveys made of other areas in Japan indicated that both the bird definitive hosts and the snail intermediate hosts were widespread. Aside from Lake Shinji, the cases of dermatitis in the farmers of Mie Prefecture as well as those of Aichi Prefecture were believed to be caused by the cercariae of *G. sturniae* (Oda, 1956a, 1956b). It is possible that there are other areas in Japan where koganbyo exists.

Yamaguti (1941) reported the presence of avian schistosomes in Japanese birds and described two new species: *Trichobilharzia corvi* (Yamaguti, 1941) McMullen and Beaver, 1945, from *Corvus corone corone* Linn., and *Ornithobilharzia emberizae* Yamaguti, 1941, from *Emberiza sulphurata* Temm. et Schleg. However, it is not known if these parasites are capable of producing cercarial dermatitis.

An interesting report was made by Ito (1956) on a brackish water furcocercous cercaria from a snail intermediate host, *Tympanotonus microptera* (Kiener) found in Chiba Prefecture (Tokyo Bay). The author named it *Cercaria tympanotoni* and suggested that on morphological grounds this cercaria might be dermatitis producing. Because of an insufficiency of snails infected with this parasite, no experimental data were obtained. However, this record indicates, for the first time in Japan, that perhaps in a brackish water environment there is a possibility of humans contracting cercarial dermatitis.

5. *China and Formosa*

There are no reported cases in man of avian cercarial dermatitis in China or Formosa. However, two species of bird schistosomes have been found in China; *Ornithobilharzia odhneri* Faust, 1924, from the Asiatic curlew, and *Ornithobilharzia hoepplii* Tang, 1951, from Swinhoe's snipe.

In Formosa, one species of avian schistosome, *Trichobilharzia yokogawai* (Oiso, 1927) McMullen and Beaver, 1945, has been isolated from the duck. The "nonhuman zoophilic" strain of *Schistosoma japonicum* in Formosa has been regarded as a dog strain, because there is a high incidence (62 per cent) of natural infections in dogs but no known occurrence in humans (Hsu *et al.*, 1954). In order to determine the effectiveness of this strain in causing cercarial dermatitis and other symptoms in man, Hsu and Hsu (1956) tested the infectivity of this strain of *S. japonicum* on five human volunteers. The cercariae of *S. japonicum* did cause the sensation of itching and the development of a rash or papule. There were systemic clinical signs, such as abdominal pain, headache, nausea,

anorexia, chest pain, and general malaise, which are normally absent from avian schistosome cercarial infection. Nevertheless, the Formosan strain of *S. japonicum* did not develop to maturity in the volunteers and consequently did not result in a typical schistosomiasis. There were no experiments on repeated infections in these volunteers to determine hypersensitivity reactions.

Japanese investigators had long suspected that *S. japonicum* ("human strain") might cause cercarial dermatitis. In 1909, Kobayashi studied the relations between "kabure," endemic dermatitis, and schistosomiasis japonica (Faust, 1924*b*). Recently Ishii and Ogawa (1952) reported that it was possible to produce dermatitis in rats with the cercariae of *S. japonicum* ("human strain") by repeated exposure to the cercariae. Characteristic lesions included macules, papules, erythema, edema, and vesicles. However, Hunter and his associates (1956), using mice, hamsters, and rabbits as experimental animals, were unable to repeat these results or similar findings reported by other workers and so concluded that the selection of the proper experimental hosts for studies on immunologic responses to schistosome infection is of critical importance.

6. *Malaya and the Philippines*

Buckley (1928) demonstrated that the dermatitis known as "sawah itch" in Malaya was caused by the cercariae of *Schistosoma spindale* Montgomery, 1906, obtained from *Planorbis pfeifferi*. Normally *S. spindale* causes serious schistosomiasis in mammals such as cattle, sheep, goats, horses, antelopes, and water buffaloes in India, South Africa, and Sumatra.

Another example of a mammal-infecting schistosome which causes dermatitis in man is *Schistosomatium douthitti* (Cort, 1914). This organism is found in the United States as a parasite in deer, mice, and muskrats.

A fruitful field for research would be a comparative study to determine the differences between the mammalian schistosomes,

which can cause dermatitis in man (like *S. spindale*, *S. douthitti*), and the dog-infecting strain of schistosome (*S. japonicum*), which apparently does not cause natural cercarial dermatitis (koganbyo) among Formosan farmers.

Recently a bird schistosome belonging to the "*elvae*" group of cercariae was described by Sandosham (1953) as the cause of sawah itch in the Ayer-Lunging district, Negri Semilan, and the intermediate host was identified as *Lymnaea rosseana* Mabille. This dermatitis-producing cercaria was named *Cercaria Malaya I*, and an unsuccessful attempt was made to infect chickens with it.

Cercarial dermatitis in man in the Philippines has not been studied to any extent, probably because of the intense efforts on the part of the medical scientists to control the spread of schistosomiasis japonica. Tubangui (1947) listed *Austrobilharzia bayensis* Tubangui, 1933, as a schistosome from the mesenteric vein of a snipe, *Capella gallinago gallinago*. This finding is encouraging for those who are interested in further host examinations for the presence of avian schistosomiasis, especially in the sea and shore birds of the Philippines.

7. *New Zealand*

According to Macfarlane (1944, 1949*a*, 1949*b*) the reports of swimmer's itch derived from lakes Hawea, Te Anau, Alexandrina, and Rotoiti, and from several lakes in the Rotorua district, have not been confirmed. However, Macfarlane recovered schistosome cercariae from snails in lakes Wanaka, Hayes, and Wakatipu in the South Island. The etiological agent causing experimental dermatitis has been described and named *Cercaria longicauda* Macfarlane, 1944. The snail intermediate hosts are: *Myxas ampulla*, *M. arguta*, and *Limnaea alfredi*. The molluscan hosts in Lake Wanaka lived in beds of the pond weed *Myriophyllum robustum* and also on *Isoetes* spp., *Juncus* spp., and *Potamogeton polygonifolium*. In lakes Wakatipu and Hayes there were

fewer snails, associated with the weed *Ranunculus fluitans*. The definitive host, the teal *Fuligula novae zealandii*, rested on the weed beds through the summer and fed on the lake floor. The adult stage of *C. longicauda* has not been studied.

8. *Australia*

Fresh-water cercarial dermatitis has been known in Australia since Johnston (1941) first reported its presence in the Murray Valley swamps. He surmised that *Cercaria parocellata* Johnston and Simpson, 1939, from *Limnaea lessoni*, on morphological grounds, might be the parasite involved. Macfarlane (1952) made a further investigation and obtained reports of dermatitis at Albury, Birri, Loxton, Mannum, Murray Bridge, and Tailem Bend near Adelaide. According to this author, at all of these places the river spread into areas of shallow water, which allowed the molluscan hosts to build up a population in close association with water birds. He believed that most of the infection of humans occurred during periods of shallow water.

Swimmer's itch was also known to be present in Western Australia. Lake Bumbleyung in the Wagin region appeared to be the important area although other smaller lakes had also been the source of the infection. The third area in Australia suspected to have cercarial dermatitis was Narrabeen Lake, a small shallow coastal lake near Sidney. It has been reported since that these cases were caused by marine species of bird schistosomes, because this lake has an outlet to the Pacific Ocean and the water may not be fresh.

Macfarlane reported that the snail intermediate host *L. lessoni* occurred in both the Murray Swamp area and the Wagin region. Whether or not *Cercaria paracellata* was involved in both areas is not known. In the Murray River, *L. lessoni* lived in the often stagnant backwaters.

Johnston (1941) suspected that the black swan was the definitive host for *C. parocellata*, but confirmation has not been made. *Cercaria jaenschi* was reported by Macfarlane (1952) not to penetrate the skin of man even though it was a schistosome cercaria. Furthermore, the antigen prepared from these cercariae produced smaller and less persistent skin reactions than did the *C. parocellata* antigen.

B. MARINE CERCARIAL DERMATITIS

1. *California and Mexico*

Extended studies of marine snails as possible agents in the transmission of cercarial dermatitis were not made until several years after World War II. However, as early as 1942, Penner mentioned that the marine gastropods might be infected with dermatitis-producing schistosome cercariae. In 1950, he described as a new species *Cercaria littorinalinae* from the marine snail *Littorina planaxis* Philippi, which were collected along the rocky shores of the Coronado Islands in Mexico and from Bird Rock near La Jolla, California. The natural definitive host was the Wyman western gull (*Larus occidentalis wymani* Dicky and van Rossem). Penner (1953c) was able to infect experimentally with this species of cercaria the following birds: brant, cormorant, black-crowned night heron, western gull, budgerigar parakeet, Australian zebra finch, domestic pigeon, red jungle fowl, and linnet. The domestic duck did not appear to be susceptible to the infection. The adults of *C. littorinalinae* belong to the genus *Austrobilharzia* (Johnston, 1917) and have been given the name *Austrobilharzia littorinalinae* by Penner although the taxonomic description is still unavailable. This species of schistosome is therefore distinct from *A. variglandis* (Miller and Northup, 1926) Penner, 1953 (= *Microbilharzia variglandis* (Miller and Northup, 1926) Stunkard and Hinchliffe, 1951).

In the San Diego area, this marine species of bird schistosome has not been officially incriminated in cases of swimmer's itch although Penner (1950) did mention that he experienced the development of typical lesions after wading in sea water in this area

while collecting the snail intermediate hosts. Cercarial dermatitis can be produced experimentally with *C. littorinalinae.*

Recently Gradhaus and Keh (unpublished data, 1957) reported cases of swimmer's itch occurring on the beaches of the city of Alameda, bordering San Francisco Bay. *Nassarius obsoletus*, a marine snail intermediate host for *A. variglandis* on the Atlantic coast, was also the intermediate host in California. It was believed that the snails were introduced into this area together with the oysters that had been planted in the bay. The schistosome cercariae from these snails were identified as those of *A. variglandis.*

2. *Hawaiian Islands*

Chu (1952) first reported the presence of a dermatitis-producing schistosome cercaria from the marine snail *Littorina pintado* Wood in two bird refuges on small offshore islands near Oahu, known as Bird Island (Moku Manu) and Rabbit Island (Manana). The snails infected with schistosomes were found only in the sea benches where there were many small tidal pools constantly receiving a sea spray. Collectors of the snails from the sea benches of Rabbit Island experienced itching and, in some cases, developed typical schistosome papule lesions on their feet. It may be added that the distribution of infectious cercariae seems to be limited to the bird refuges, because Chu and Cutress (unpublished data, 1954) were unable to find schistosome-infected snails inhabiting any of the swimming beaches on the major islands of Oahu, Maui, Kauai, and Hawaii. The life history of this parasite has been reported by Chu and Cutress (1954). The natural definitive host for the adult stage was the ruddy turnstone (*Arenaria interpres interpres*), a shore bird which winters in the Hawaiian Islands. Chicks, ducks, and the sooty and noddy terns could be infected experimentally.

After a study of the morphological characters of the adult stage of the schistosome in the naturally infected turnstones as well as in

the experimentally infected animals, the authors concluded that this species was the same as the species of schistosome reported by Stunkard and Hinchliffe (1951, 1952) from the eastern United States along the Atlantic Ocean, i. e., *Austrobilharzia variglandis.*

Penner (1953*b*) reported that the red-breasted merganser (*Mergus serrator* L.) was the natural definitive host for *A. variglandis* in the Atlantic coast. Munro (1944) states that this species of bird had been reported only as an occasional visitor to the Hawaiian Islands. However, Richardson and Fisher (1950) do not list the red-breasted merganser as a species found in the Hawaiian bird refuges. It can also be added that the western gull, a natural definitive host for *A. littorinalinae* in California, is not a species generally seen on Oahu.

The migration routes for shore birds in the Pacific Ocean have been studied by Baker (1951). On the basis of sight records, specimen collection, known statistics of breeding and wintering, and from a study of maps of the region, he established the following three flyways: (1) the Asiatic-Palauan, (2) the Japanese-Marianan, and (3) the Nearctic-Hawaiian. For each of the flyways the author listed the names of the regularly visiting and the uncommonly visiting shore birds. Of the 35 species mentioned, only the ruddy turnstone and the golden plover (*Pluvialis dominica fulva*) were the ones common to all of the three flyways. In the experience of the Hawaiian investigators, the golden plover was never found to be infected with the schistosome, in contrast to the ruddy turnstone.

King (1955) listed six major groups of sea birds found in the central Pacific Ocean. These are: (1) the albatrosses, (2) the shearwaters and petrels, (3) the terns, (4) the frigate birds, (5) the boobies, and (6) the tropic birds. Gulls and jaegers were listed as being occasionally seen. Chu and Cutress (unpublished data, 1954) did not encounter a single case of natural infection with schistosomes in limited examinations of sea bird pop-

ulations. The exact relation of the sea birds to the problem of transmission and reservoir hosts in Hawaii has yet to be determined.

The snail intermediate host, *L. pintado*, uncommon in Micronesia and apparently limited in its range to the northern Pacific islands, has been reported by Demond (1957) to exist in southern Japan, the Ryukyus, Bonins, northern Philippines, Marianas, Marshalls[4], Johnston Island, and Formosa. The experimental snail intermediate host used by Chu and Cutress, *Littorina scabra* L., has a much wider geographical range: from east Africa through the Indian and Pacific oceans to Hawaii and Tahiti, and from the Ryukyus, the Philippines, and Marianas, south to northern Australia. Since both the definitive and intermediate hosts for *A. variglandis* are widely spread in the Pacific area, one may surmise that marine schistosome infections of birds and snails may not be limited to the Hawaiian Islands and California and that with further investigation other areas might prove to be infected.

In determining the casual agent of swimmer's itch, or cercarial dermatitis, it is not sufficient to find schistosome-infected snails in the area because of the possible presence of other etiological agents which cause similar skin lesions. "Swimmers' Itch" (or "Pearl Harbor Itch") cases reported by Arnold and Bonnet (1950) are now suspected to have been cases of marine hydroid dermatitis, because the discovery of a medusa (*Sarsia* sp.) was made in the same location which Arnold and Bonnet reported to be a source of the dermatitis. This finding, together with the absence of schistosome-infected snails in the areas under study, suggests that these "Swimmers' Itch" cases of Arnold and Bonnet were not of cercarial origin (Chu and Cutress, unpublished data).

It is necessary, however, to point out that

in the Atlantic coast, (such as Mill cove in Maine, Narragansett Bay in Rhode Island, and Long Island Sound, N. Y.) cercarial dermatitis was reported to be associated with clam digging (Orris and Combs, 1950; Sindermann and Gibbs, 1953). The intermediate host is a mud snail, *Nassarius obsoletus* (*Nassa obsoleta*), which is also an intermediate host for the marine schistosome in California. This species is not found in Hawaii as Edmondson (1946) listed *Nassa sertum* Bruguiere as the only local species. In several surveys made during 1951–54 by the Hawaiian investigators, the few bottom-dwelling gastropods from West Loch, Pearl Harbor, were never found to be infected with schistosome parasites.

Demond (1957) listed *Nassarius papillosus* (Linn.) as occurring in Hawaii. As yet, there is no report indicating that this or any other species of *Nassarius* is an intermediate host for schistosome in the central and south Pacific.

An example of the difficulty of determining the etiological agent for dermatitis caused by marine microorganisms is that reported by Strauss (1956) for the "Seabather's Eruption" in Guantanamo Bay, Cuba. This investigator was unable to find any snails infected with schistosomes. Serological tests of the patients showed negative evidence for the presence of cercarial dermatitis. A more fortunate experience than that reported by Strauss was given by Chu and Cutress (1955). Many construction workers contracted dermatitis when in contact with sea water in Hilo Bay, Hawaii. Although in this area, *Littorina pintado* and the ruddy turnstone were seen, no schistosome-infected snails were located. Instead, a marine hydroid, *Syncoryne mirabilis* (Agassiz, 1852), was found growing profusely on the surface of the submerged rocks near the site of construction. By chemical treatment, the hydroids were destroyed and the dermatitis was controlled.

Most of the conclusions incriminating marine schistosome cercariae in cases of derma-

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[4] In 1955, at Eniwetok, C. E. Cutress found *L. pintado* and ruddy turnstones in the area, but among the specimens examined by him no schistosomes were found (personal communication, 1957).

titis have been based upon circumstantial evidence. The urgent need in diagnosing the cause of naturally occurring dermatitis is a technic (e. g., biopsy tests) which would yield direct evidence about the infective agent, so that proper control methods could be formulated.

3. *Australia*

Bearup (1955, 1956) showed that schistosome cercariae occurred in a marine snail, *Pyrazus australis* Quoy and Gaimard, in Narrabeen Lake, near Sydney, N. S. W. The cercaria was first identified as *Cercaria variglandis* later Miller and Northup, subspecies *pyrazi*, but was determined to be the cercaria of *Austrobilharzia terrigalensis* Johnston, 1917. The seagulls (*Larus novae-hollandiae*) from the Sydney district were heavily infected.

The incidence of schistosome infection in *P. australis* from Narrabeen Lagoon was 4–6 per cent, the higher level occurring during the hot months at the end of the year. Cercariae from these infected snails would infect young seagulls, budgerigars (*Melopsitacus undulatus*), and pigeons (*Columba livia*), but not domestic ducks or mice.

From Florida, U. S. A., several marine schistosome cercariae have been described (Hutton, 1952; Leigh, 1955; Penner, 1953a). These species are distinct from one another and different from *A. variglandis*. However, the extreme similarity in morphology of the three species, namely, (1) *A. variglandis* from the Atlantic, Pacific, and Hawaiian areas, (2) *A. littorinalinae* from southern California and Mexico, and (3) *A. terrigalensis* from Australia, raises the interesting question of whether or not they are actually one species with minor variations because of adaptation to the intermediate and definitive hosts in widely separated geographical areas.

DISCUSSION

Cercarial dermatitis is of worldwide distribution, and probably there are other areas where suspected cases of swimmer's itch occur but where no investigations have been made. In the Pacific Ocean area, many islands in the Polynesian, Micronesian, and Melanesian groups are worthy of exploratory studies for the presence of bird schistosomiasis. Likewise, other geographical areas such as China, Formosa, Indonesia, Viet Nam, the Philippines, and Thailand have yet to be investigated fully.

In the North American continent, swimmer's itch has been widely studied, yet data on schistosome infections in migratory birds are still limited. Most of the information on definitive hosts has been obtained through experimental infection. As a result, the question is frequently asked as to the degree of natural infection with schistosomes in other types of birds. In this connection, the problem of host susceptibility has been studied by many investigators. In our own experience, the marine schistosome adults found in the ruddy turnstone developed well in the sooty and noddy terns, but in chicks and ducks the adults did not remain viable for an extended period and the pathology was not entirely comparable to that in the natural host. This differential susceptibility between species and subspecies (or strains) of the birds is a challenging problem to workers who are interested in immunology. Such a study is important in relationship to speciation and distribution of both the fresh-water and marine schistosomes in birds.

Specificity of a trematode parasite for a host may be directly correlated with the host diet. An example of this correlation was reported by Oguri and Chu (1955) for the infection of domestic ducks by the cloacal trematode *Parochis acanthus* (Nicoll, 1906) Nicoll, 1907. The natural definitive hosts for this parasite are sea birds. When the infectious cysts of *P. acanthus* were given orally to mash-fed ducks, there were no infections in these experimental hosts. However, if the ducks were fed with squids from the sea, instead of the mash diet, it was possible to establish the

infection in them. This variation in host susceptibility caused by a change in diet suggests that seemingly contradictory results from host experimental infections for bird schistosomes may be due to differences in the diets fed the experimental hosts by the various investigators.

Substantial data, on the other hand, have accumulated during the past several decades regarding the bionomics of the intermediate hosts of the dermatitis-producing schistosomes. These data are chiefly concerned with (1) the habits of the snails, such as their food requirements, reproductive rates, adaptation to surroundings, and association with other plant and animal life, (2) the environmental conditions such as changes in pH and salinity in water, variation in temperature and amount of sunlight, and (3) susceptibility of the other species of snails in the locality to infection by the schistosome miracidia. This information is essential for understanding the reasons why the disease exists in specific localities. Many reports also indicate that an intimate association between the infected birds and the snail intermediate hosts is a necessity before cercarial dermatitis can be established as a "Disease of the Place."

For fresh-water snails, cultivation in the laboratory has not been a problem, but for marine snails, technics for their cultivation are yet to be developed. The bionomics of marine snails is a fascinating subject. Edmondson (1946) stated that: "A specimen of *Littorina pintado* remained attached to the plastered wall of the Marine Biological Laboratory, Honolulu, for nearly a year. When it was returned to sea water it regained its activity in a few minutes." Attempts are now being made to breed *Littorina* snails in our laboratory for use in experimental work on schistosomes.

The investigation of all phases concerned with marine cercarial dermatitis is indeed a green pasture for those who are interested in diseases associated with a marine environment. We encourage investigators in the Pa-

cific area to participate in this field of study.

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Some Observations on the Lagoon Plankton of Eniwetok Atoll[1]

MALVERN GILMARTIN[2]

DURING THE COURSE OF a translagoon eco-
logical study conducted in the northern
Marshall Islands during 1955, a series of
plankton hauls were taken. Subsequent analy-
sis revealed several interesting aspects of
lagoon plankton, in addition to recording the
forms present.

Eniwetok Atoll lies at about 11° 30′ N.
latitude and 162° 15′ W. longitude. The atoll
is composed of 38 islets on a reef surrounding
an oval lagoon approximately 30 kilometers
wide and 40 kilometers long. The lagoon is
essentially a self-contained body of water with
a maximum depth of 65 meters. There are 3
major passes between the lagoon and the open
ocean; southeast pass, 550 meters wide with
an average depth of 31 meters, south pass,
9.5 kilometers wide with an average depth of
18 meters, and southwest pass, 4.3 kilometers
wide with an average depth of 7 meters.

From 4 April 1955 to 29 December 1955,
21 plankton hauls were made along a transect
extending from between Giriinien and Rigili
islets to Aniyaanii Islet (Fig. 1). Each indi-
vidual series contained a haul made just in-
side the reef on the east end of the transect,
from 1 to 3 hauls equidistantly placed along
the transect, and a haul taken just inside the
reef on the west end of the transect. All series
were completed during periods within 2½
hours of local apparent noon. Individual
series were taken at speeds from 1 to 2½ knots
at depths ranging from 1 to 3 meters. The
plankton collected were stored in 10 per cent
sea water–formalin for subsequent treatment.
All hauls were taken using a one-half meter

plankton net constructed for quantitative
work (Tester, 1955) with an internally mount-
ed Atlas-style flow meter.

During this period, standard oceanographic
observations were made. The mean value,
range, and standard deviation of certain phys-
ical and chemical characteristics of the transect
surface water is indicated below.

	Tempera- ture °C.	Salinity °/oo	Oxygen % sat.
mean	28.61	34.37	90.0
range	28.31–29.13	34.05–34.67	59.9–104.7
σ	.023	.046	7.9

No apparent correlation was noted between
these factors and the intralagoon plankton
distribution.

The results of the plankton hauls, as indi-
cated for occurrence in Table 1, for dominance
in Figure 2, and for volume in Figure 3, sug-
gest a surprisingly "endemic" (as opposed to
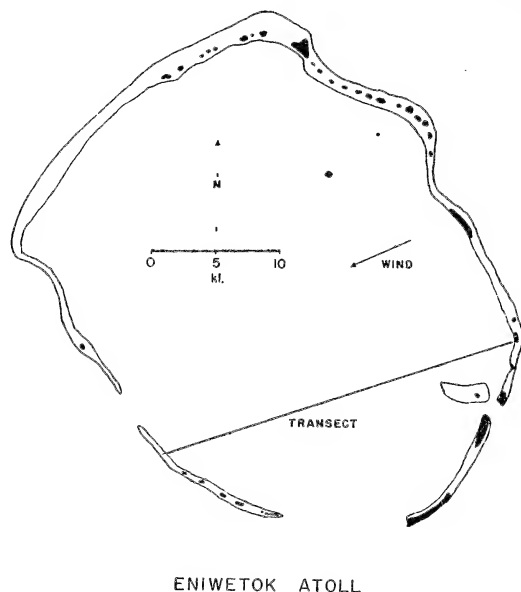
ENIWETOK ATOLL

FIG. 1. Eniwetok Atoll showing transect line.

TABLE 1

ABUNDANCE OF PLANKTON CONSTITUENTS BY HAUL
A = abundant, 5 per cent or more by number; C = common, 1–5 per cent by number;
S = scarce, less than 1 per cent by number

	PLANKTON HAUL AND DATE																				
	April 4				Nov. 10					Nov. 13			Dec. 26				Dec. 29				
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
Cyanophyta:																					
Trichodesmium erythraeum		S							S	S	S										
Chrysophyta:																					
Coscinodiscus sp.						C							S				C	C	C	S	
Protozoa:																					
Foraminifera sp.						S	S	S	S	S				S	S	S		S	S		S
Radiolaria sp.								S			S				S	A	S	S			
Coelenterata:																					
Anthozoa sp. (sea anemone)																	S				
Scyphozoa sp.	S	A	S	A	S	A	A	A	S	A	A	C	S	S		A	C				S
Siphonophora sp.	S		S	A	S				S			C			C	C	C		C	C	C
Ctenophora:	S	A	A														S				
Brachiopoda:																					
Lingula sp. larva	S	S	S		S	S									S						
Echinodermata:																					
Ophiuroidea sp. larva							C					S									
young adult																S					
Echinoidea sp. larva									S												
Chaetognatha:																					
Sagitta sp.	S																		C		
Sagitta enflata	A	A	A	A	A	A	A	A	A	C	A	C	A	A	A	S	C	C	C	C	C
Sagitta neglecta	S				S	A														C	S
Sagitta regularis					S				S											C	S
Mollusca:																					
Heteropoda																					
sp. larva																	S				
Atlanta sp.		S				S	S	S	S		S	S			S					S	A
Pteropoda																					
sp.																					
Creseis virgula								S		C	S										
Gastropoda																					
sp. larva		S			S	S	S	S	S	S		S		S	S		S	S	S		
Natica sp. larva		S				S					S	S									
Annelida:																					
sp. larva	S				S	S		S		S								S			
Arthropoda:																					
Copepoda sp.		S					S	S	S								S				
Arcartia sp.																		S			
Candacia ethiopica											S						S	S	S		
Centropages calanius											S						S		S	S	S
Copilia mirabilis										S											
Corycaeus sp.											S							S		S	
Euchaeta marina				S														S			
Labidocera sp.		S			S																
Labidocera laevidentata										S											
Macrosetella gracilis															S						
Neocalanus gracilis									S												
Onceae sp.										S											
Arthropoda:																					
Pontellina plumata						S						S						S			
Pontellopsis sp.										S		S							S		

TABLE 1 (Continued)

ABUNDANCE OF PLANKTON CONSTITUENTS BY HAUL

A=abundant, 5 per cent or more by number; C=common, 1–5 per cent by number;
S=scarce, less than 1 per cent by number

| | April 4 | | | | Nov. 10 | | | | | Nov. 13 | | | Dec. 26 | | | | Dec. 29 | | | | |
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
Sapphrina sp		S									S	S							S		
Scolecithrix danae										S											
Tortanus gracilis					S																
Undinula vulgaris	C		S		S					S	S		C	C	S	S	O	C	S	S	
Amphipoda sp	S	S		S		S	S			S	S	S		S							
Isopoda sp										S											
Mysidacea sp																	S				
Euphausiacea sp									S	S		S			S					S	
Stomatopoda sp. larva		S		S	S	S		S	S		S	S			S	S		S			
Decapoda																					
Macrura larva	S		S	S	S	S	S	S	S	S	S	S	C							S	S
Anomura larva									S		S		S	S							
Brachyura zoea		C	S	S	S	S	S	A	A	C	A	A	A	A	C	S	S	S	A	A	S
Chordata:																					
Oikopleura sp	A	A	A		A	A	A		S				C	S	S	A	S	S	C	C	
Salpa sp		S					S	S	S			S									
Thalia democratica																		S			
fish eggs	S	S	S	S	S	S	S	S	S	S		S	S	C	C	C	A	A	C	C	A
Goby eggs	S	S			S	S		S					A		C		C	C			A
fish larva	S		S	S	S	S	S	S	S	S	S	S	S	S	S				O		
Monocanthus sp. larva								S													
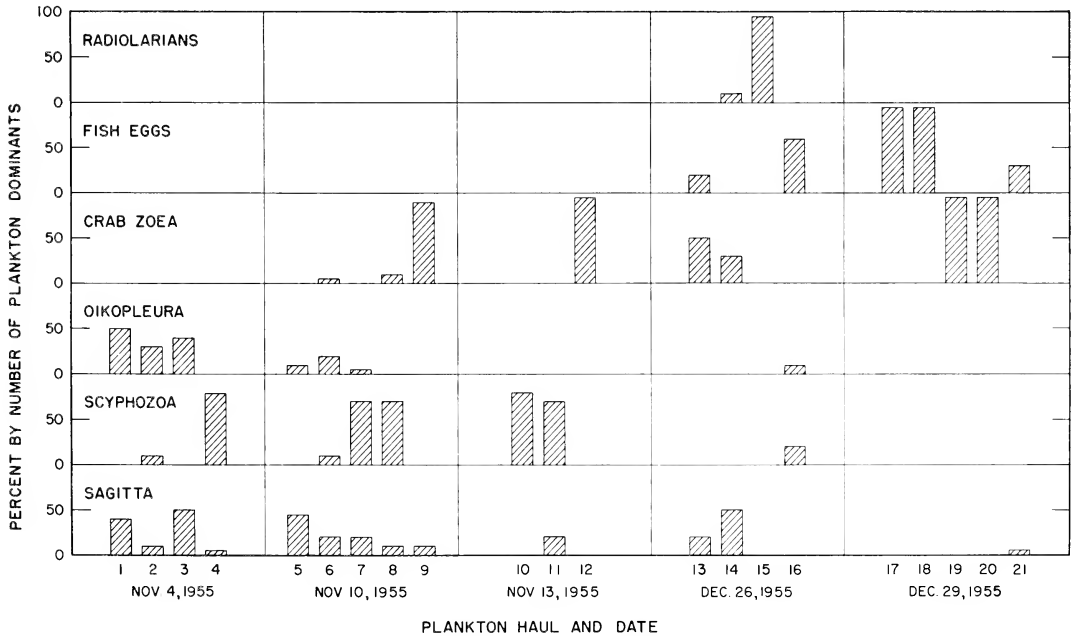
FIG. 2. Relative plankton constituents.
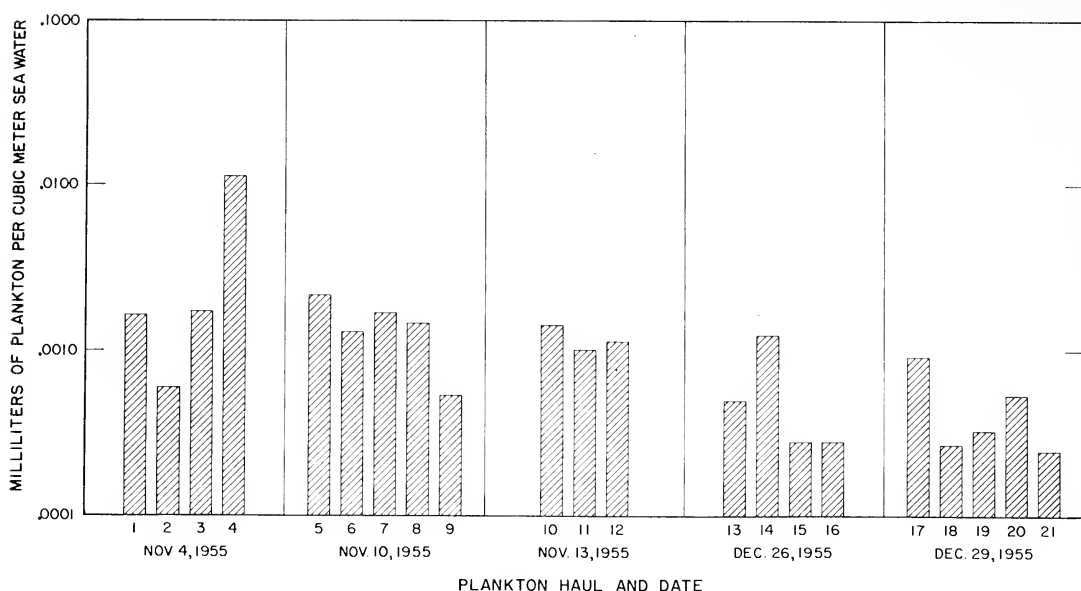
Fig. 3. Plankton settling volumes.

"transient") lagoon plankton population compared with that reported from other northern Marshall Islands atolls (Johnson, 1954). An analysis of the plankton dominants show that over half of the hauls were dominated by meroplanktonic forms, e.g., brachyura zoea, or groups the majority of which are neritic, e.g., scyphozoan medusea. In some of the hauls, these forms made up 95 per cent of the number of planktants collected. Certain of the species noted, e.g., *Undinula vulgaris*, have relatively long life cycles. For these and the noted meroplanktonic forms to maintain the relative concentrations indicated by these hauls would suggest a relatively stable body of lagoon

water. The lack of numerous deep passes between the ocean and the lagoon, common in other northern Marshall Islands atolls, might explain this indicated restriction in water exchange.

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On Certain Thaliacea (Tunicata) from the Pacific Ocean, with Descriptions of Two New Species of Doliolids[1]

TAKASI TOKIOKA[2] and LEO BERNER[3]

THE MATERIAL upon which this paper is based has been taken from the extensive plankton collections available at the Scripps Institution of Oceanography. The samples examined were from three sources: the Shellback Expedition to the area off Central and South America in 1952, the Mid-Pacific Expedition to the Marshall Islands area in 1950, and from the routine Marine Life Research Program sampling off the west coast of the United States and Baja California, Mexico. The two expeditions were in part supported by grants from the Office of Naval Research. The Marine Life Research Program is the Scripps Institution's component of the California Cooperative Oceanic Fisheries Investigations, a project sponsored by the Marine Research Committee of California. The work has been further supported by a postdoctoral grant from the Rockefeller Foundation for the senior author.

Two new doliolids found in the plankton samples collected on the Shellback Expedition have already been described (Tokioka and Berner, 1957), and further examination of the samples has yielded two additional new doliolids from the same area.

In addition to the descriptions of the two new species, both of which belong to the genus *Doliolina*, additional notes are given on

Doliolina undulata Tokioka and Berner 1957, *Doliopsoides horizoni* Tokioka and Berner 1957, *Doliolina intermedium* (Neumann) (1906), *Cyclosalpa strongylenteron* Berner 1955, and *Cyclosalpa bakeri* Ritter 1905.

Doliolina obscura new species
Fig. 1A–E

Many specimens of this species were found at Shellback stations 137, 142, 145, 155, 160, and 180. The species also occurs quite often in the samples collected by the Marine Life Research Program, although it is never numerous.

The gonozooids may be somewhat stumpy in outline; they are usually less than 5 mm. long and may range up to 4 mm. in body diameter. The test is of moderate thickness, is rather soft, and may be easily stripped from the body. When found with the test in place the specimens tend to be covered with detrital material from the sample.

Muscles I, VII, and VIII are narrower than muscles II-VI. Muscle VII is distinctly interrupted at the mid-ventral line. The sixth and seventh intermuscular zones, especially the latter, are narrower than the others.

The endostyle (*ed.*) is long, extending anteriorly at least to three-fourths of the second intermuscular zone and posteriorly to the anterior margin of muscle V. The anterior margin of the peripharyngeal band (*p.b.*) extends nearly to muscle I. The ciliated groove (*c.g.*) is situated in the middle of the second intermuscular zone. The dorsal ganglion (*d.g.*) is
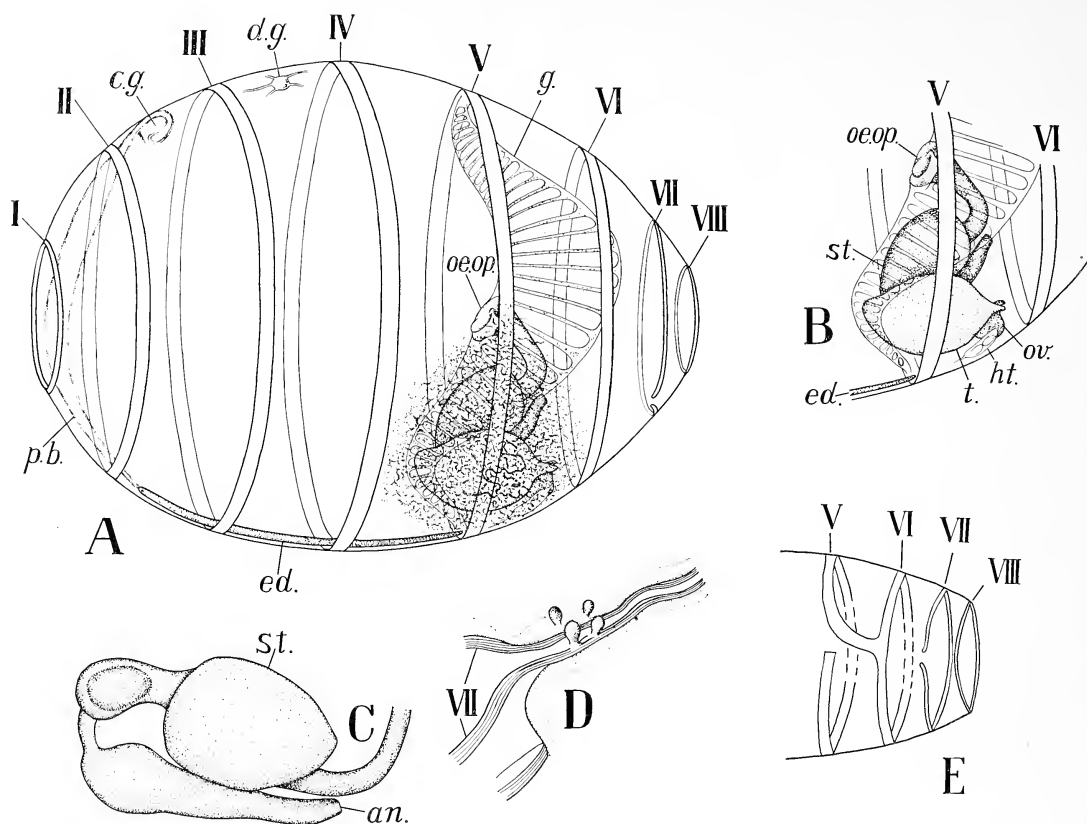
Fig. 1. *Doliolina obscura* n. sp. A, Animal from left side: a 5 mm. gonozooid. B, Alimentary organs and gonads from left side. C, Alimentary canal. D, Ventral protuberance, phorozooid. E, Aberrant form showing arrangement of muscles viewed ventrally.

Abbreviations: I–VIII, body muscles; *an.*, anus; *c.g.*, ciliated groove; *d.g.*, dorsal ganglion; *ed.*, endostyle; *g.*, gill septum; *ht.*, heart; *int.*, intestine; *oe.op.*, oesophageal opening; *ov.*, ovary; *pb.*, peripharyngeal band; *st.*, stomach; *t.*, testis; *v.d.*, vas deferens.

situated in the third intermuscular zone with its posterior edge at the center of the zone. The gill septum (*g.*) is sigmoid in shape extending from the dorsal to ventral position of muscle V, (Fig. 1*a*). At the lower flexure the anterior margin reaches slightly beyond the middle of the fourth intermuscular zone. At the upper flexure the posterior margin extends slightly beyond the posterior margin of muscle VI. The median crest of the gill septum is slightly displaced to the right side in the ventral half of its course, where the massive alimentary organs and gonads are situated. There are about 40 elongate stigmata.

The alimentary organs and gonads are surrounded by densely aggregated corpuscles which make it very difficult to examine the structure of the organs closely. These corpuscles are probably reddish orange when the animal is alive. Staining of the specimens with Rose Bengal makes it somewhat easier to study this portion of the body.

The oesophageal opening (*oe. op.*) is located near the center of the circle described by muscle V. The stomach (*st.*) is located on the sagittal plane of the body and is roughly oval in outline. The intestine forms a simple loop and ends with the anus (*an.*) at a posi-

tion slightly behind the cardiac end of the stomach. The hind stomach is distinct and there is an obvious constriction between it and the following portions of the gut.

The ovary (*ov.*) is located near the middle of the fifth intermuscular zone or slightly posterior to it. The testis (*t.*) is a fusiform-shaped stumpy mass, oriented anteroposteriorly, and extending from the ovary to near the middle of the fourth intermuscular zone. The heart is located near the ovary.

The phorozooid is similar in appearance to the gonozooid, though the corpuscular aggregation over the area of the gut tends to be reduced in the phorozooid. Both the ventral ends of muscle VII extend into the ventral protuberance (Fig. 1D).

At a glance this new species closely resembles *D. mülleri* (Krohn 1852). It differs from the latter by having the ventral interruption of muscle VII and in the anterior-posterior position of the testis. In *D. mülleri* the testis is situated somewhat dorsoventrally and muscle VII forms a complete loop. The sigmoid curve of the gill resembles *D. sigmoides* Garstang 1933 (= *Doliolum krohni* Neumann 1906). The new species completely lacks the epidermal tentaclelike processes characteristic of *D. sigmoides*. Interrupted muscle VII is another differentiating characteristic. The new species differs from *D. undulata* in the shape of the stomach and in the shape and location of the testis. In addition, the aggregation of corpuscles around the alimentary organs and the gonads is unique. The species name comes from this aggregation which makes these organs obscure.

The specimens upon which this description is in part based are deposited in the U.S. National Museum under the following numbers: HOLOTYPE: U.S.N.M. no. 11371, *Doliolina obscura*, gonozooid, 1 specimen from Shellback station 137 located at 13° 43.5′ S. 81° 08.5′ W.

PARATYPES: U.S.N.M. no. 11372, gonozooids, 10 specimens, *Doliolina obscura* from Shellback station 137.

From the MLR material one aberrant form was taken in which the fifth body muscle was interrupted and the left limb of that muscle extended back to connect with muscle VI. In other respects this specimen did not differ from the species. The muscle arrangement is shown in Figure 1E.

Doliolina separata new species
Fig. 2

A few specimens of this diminutive doliolid were found in the samples from Shellback stations 137, 145, and 180. Most of them were poorly preserved and immature, but three mature, fairly well-preserved specimens were found at station 137. The following description is based on these three specimens.

The specimens were 1.5, 1.7, and 1.7 mm. long. The body is somewhat elongate. The test is of moderate thickness and is easily stripped from the body. Under the microscope many minute cells can be observed on the surface of the test.

Body muscles I, VII, and VIII are very narrow. Muscle II is somewhat narrower than muscles III-VI. Muscle VII is clearly interrupted at the mid-ventral line. The first and seventh intermuscular zones are narrower than the others.

The endostyle (*ed.*) is very long, extending from the posterior margin of muscle II to near the anterior margin of muscle V. The anterior border of the peripharyngeal band (*p.b.*) closely approaches muscle I. The ciliated groove (*c.g.*) is situated approximately in the middle of the second intermuscular zone. The dorsal ganglion (*d.g.*) is located in the third intermuscular zone near the posterior margin of muscle III. The gill septum (*g.*) extends from muscle VI dorsally to muscle V ventrally, and bears 10 pairs of somewhat elongate stigmata.

The oesophageal opening is located at the center of the circle formed by muscle VI. The whole alimentary canal forms an S-shaped loop towards the anteroventral side, in the
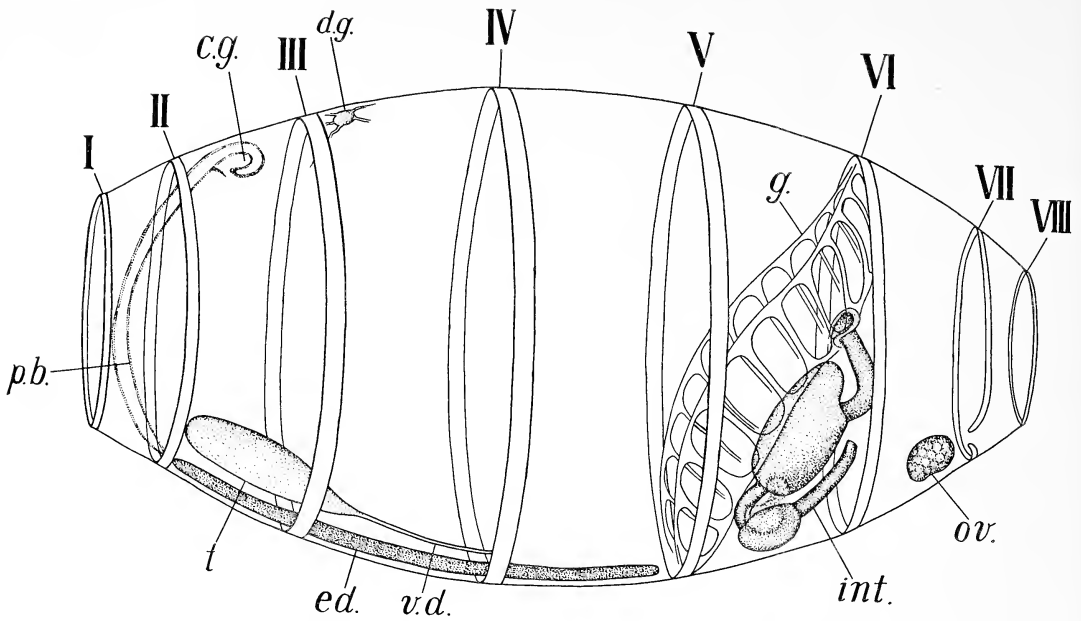
FIG. 2. *Doliolina separata* n. sp., a 1.7 mm. gonozooid from left side.

sagittal plane of the body. The stomach is roughly an elongate ellipse in outline with its cardiac portion prominently protruded. The anus opens near the cardiac end of the stomach. The anterior margin of the intestinal loop (*int.*) extends to near the posterior margin of muscle V. The mid-intestinal region is swollen in some specimens. Usually there is a small group of cells on each side of the intestinal loop, in some cases these groups may consist of two parts, one large and one small.

The ovary (*ov.*) is situated ventrally near the middle of the sixth intermuscular zone. The testis (*t.*) is a club-shaped organ extending from the posterior margin of muscle II to slightly beyond the posterior margin of muscle III. The vas deferens (*v.d.*) opens into the pharynx at the level of muscle IV.

The phorozooid is quite similar to the gonozooid. It lacks gonads and has a ventral protuberance, into which the ends of muscle VII project.

Doliolina separata n. sp. resembles *D. krohni* (Herdman 1888) and *D. indicum* (Neumann 1906) in that it has an obliquely stretched gill

septum. The shape of the testis is somewhat reminiscent of *D. intermedium* (Neumann 1906). The ventral interruption of muscle VII and the peculiar arrangement of the gonads, in which the ovary and testis are widely separated from each other, is unique and this latter characteristic is the basis for the specific name here given.

The material upon which this description is in part based is deposited in the U.S. National Museum:

SYNTYPES: U.S.N.M. no. 11373, 2 specimens, Gonozooid, *Doliolina separata* from Shellback station 137.

ALLOTYPES: U.S.N.M. no. 11374, 4 specimens, Phorozooid, *Doliolina separata* from Shellback station 137.

Doliolina intermedia (Neumann 1906)
Fig. 3

Doliolum intermedium Neumann, 1906: 211–212.

Many specimens of *D. intermedium* have been found in the Shellback and the Mid-

Pacific material. They have an average length of about 10 mm. The test is very soft, of moderate thickness, and is easily stripped from the animal. All eight body muscles are complete. Muscles VII and VIII are very narrow and muscle VI is somewhat narrower than muscles I-V. The third intermuscular zone is the widest and the seventh is the narrowest.

The endostyle (*ed.*) extends anteriorly to beyond the second intermuscular zone and posteriorly to the middle of the fourth zone. The anterior margin of the peripharyngeal band (*p.b.*) approaches the posterior margin of muscle I. The ciliated groove (*c.g.*) is situated in the center of the second intermuscular zone. The dorsal ganglion (*d.g.*) is located in the third intermuscular zone near the posterior margin of muscle III. The gill septum (*g.*) attaches at muscle IV dorsally at the middle, or slightly beyond, the fourth intermuscular zone ventrally. It bears about 50 pairs of elongate stigmata.

The loop of the alimentary canal is situated vertically in the fifth intermuscular zone with the oesophageal opening (*oe. op.*) on the sagittal plane. The stomach is elongate and rectangular in outline with the anterior margin slightly convex. The hind-stomach is very distinct with an extreme constriction between it and the intestine. The anus is located near the cardiac end of the stomach.

The ovary (*ov.*) is situated just in front of muscle VII. The testis (*t.*) projects anteriorly along the left side of the endostyle with its anterior portion often curving dorsally along the posterior side of the peripharyngeal band.

Doliolina undulata Tokioka and Berner 1958
Fig. 4

Doliolina undulata Tokioka and Berner, Pacific Sci. 12(2):135–138.

Several more specimens of *D. undulata* have been found in the material from the Shellback Expedition. In some of these, most frequently small mature specimens, the testis is stretched obliquely between muscles V and VI with
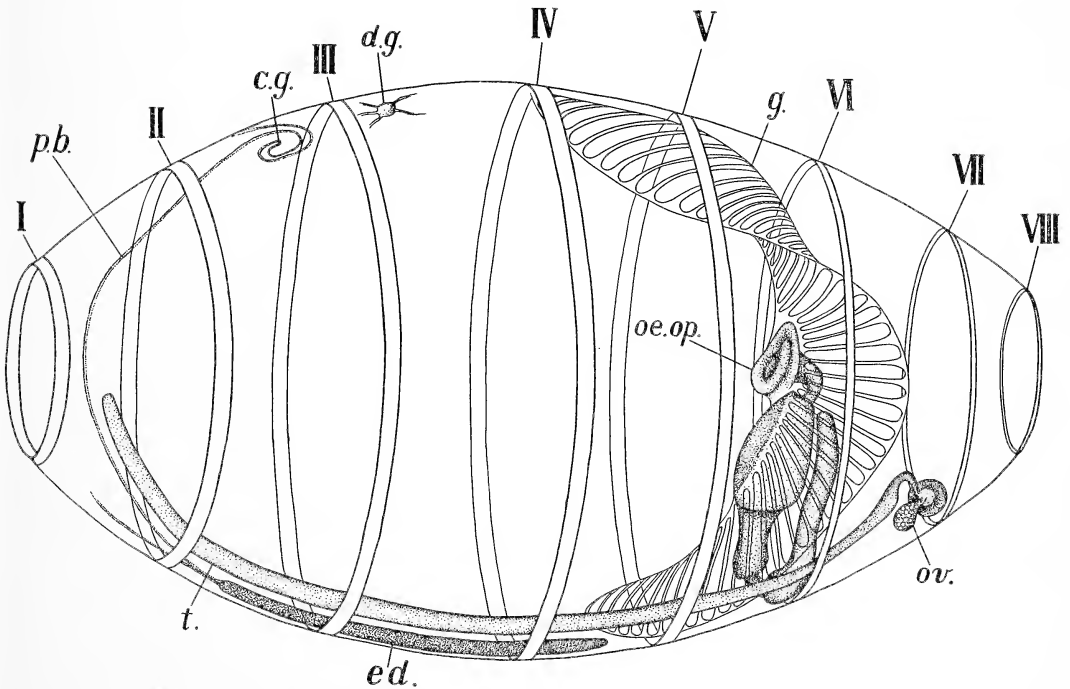
FIG. 3. *Doliolina intermedia* (Neumann) 1906, a 10 mm. gonozooid from left side.
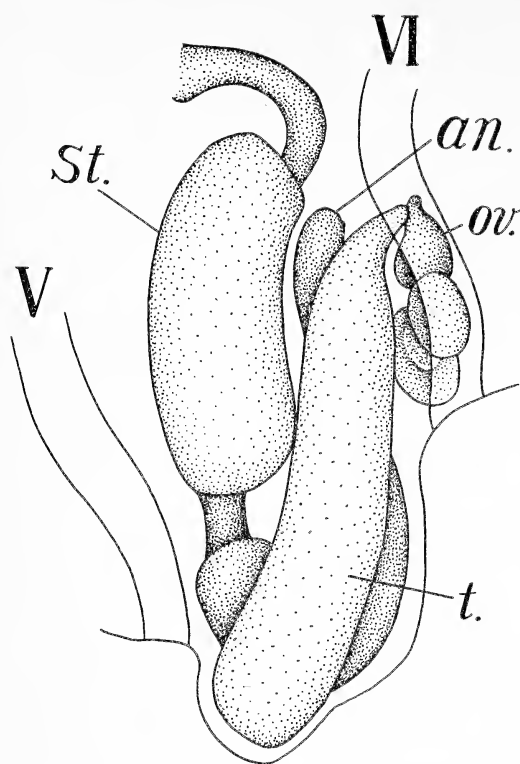
FIG. 4. *Doliolina undulata* Tokioka and Berner 1958, alimentary organs and gonads, from left side.

very little undulation. In these cases the ventral part of the body, just posterior to muscle V, is distended by the testis. The appearance of the testis and its relative position against the intestinal loop are fundamentally the same as in specimens with the undulating testis.

Subdivisions of the genus DOLIOLINA

With the descriptions of *D. undulata* Tokioka and Berner (1958) and here of *D. obscura* and *D. separata*, we find two types of muscle pattern within the genus *Doliolina*. These patterns, one in which all of the muscles form complete loops and one in which the seventh muscle is interrupted ventrally, distinctly divide the genus into two groups. On this basis we have established the following subdivision of the genus:

1) *Doliolina* perfecta: The muscle bands of this group all form complete bands. The following species are included: *indica* (Neumann

1906), *intermedia* (Neumann 1906), *resistible* (Neumann 1913), *mülleri* (Krohn 1852), *krohni* (Herdmann 1888), and *sigmoides* Garstang 1933.

2) *Doliolina* imperfecta: Within this group the seventh muscle band is always interrupted at the mid-ventral line. The species in this group are known only from the eastern Pacific Ocean, and include: *undulata* Tokioka and Berner 1958, *separata* n. sp., and *obscura* n. sp.

The shape and position of the gonad and the arrangement of the gill septum vary considerably within the two groups, and in some cases convergence of these features may be seen. We thus hesitate to treat them as subgenera of *Doliolina* but feel the problem may better be settled by more extensive collections and further critical examination of the respective species.

The discovery of three species of doliolids, in addition to the one previously known (*Dolioletta mirabilis*), in which a body muscle is interrupted gives support to the argument for the abandonment of the ordinal name Cyclomyaria for the doliolids, in favor of the name Doliolida. This change has been generally accepted since Garstang's review (1933).

Doliopsoides horizoni Tokioka and Berner 1958
Figs. 5A, B

Many additional specimens of *D. horizoni* have been found in the material from the Shellback Expedition. In some of these the alimentary organs are better preserved than in any of the previous specimens. Close examination of these organs reveals that the stomach is provided with several fingerlike protuberances. In one especially well-preserved specimen, four pairs of these protuberances were found on the ventral, posterior portion of the cardiac stomach and two pairs on the ventral, posterior portion of the pyloric stomach. The number of protuberances is not constant among the specimens.
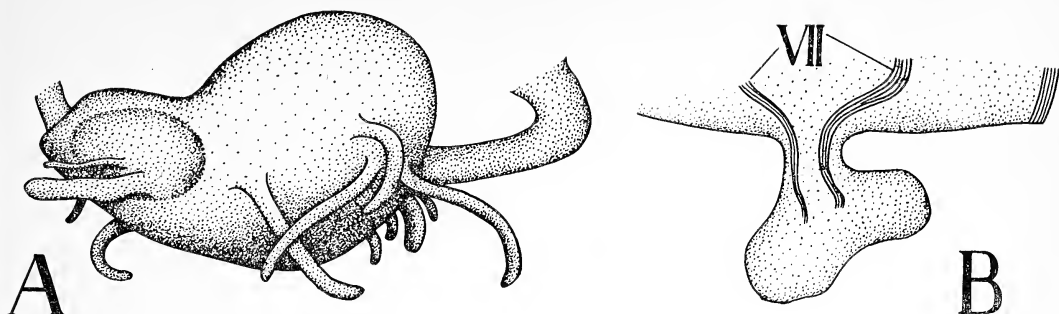
FIG. 5. A, *Doliopsoides horizoni* Tokioka and Berner 1958, stomach showing protuberances. B, *Doliopsoides horizoni*, ventral protuberance of phorozooid.

One individual of the phorozooid generation was found among the specimens. It has a short ventral protuberance into which both ends of muscle VII project.

COMPARISON OF ALIMENTARY REGION OF
Cyclosalpa strongylenteron AND *C. bakeri*

In the examination of aggregate individuals of *Cyclosalpa strongylenteron* Berner 1955, some distinct asymmetries were found in the arrangement of the alimentary organs and gonads. These features differed somewhat between the dextral and sinistral individuals, although the musculature showed almost complete symmetry. The features of the alimentary organs and the gonads are compared with those of the aggregate form of *C. bakeri* Ritter 1905, whose visceral portion closely resembles that of *C. strongylenteron*.

In *Cyclosalpa strongylenteron* Berner 1955 (Figs. 6A, B, 7) the dextral individuals are those derived from the right side of the stolon when it is placed so that the stolo-individuals are situated dorsal side up, with the posterior end toward the right and with the proximal end of the stolon pointing away from the observer. The sinistral individuals are those derived from the left side of the stolon.

In the dextral individuals the intestinal loop is U-shaped. The anus (*an.*) opens on the left side at a level slightly anterior to the oesophageal opening (*oe. op.*). There is a large elongate blind sac or caecum (*l.c.*) attached to the ventral side of the lower branch of the loop, about one third of the way between the oesophageal opening and the posterior margin of the loop. The tip of the caecum reaches posteriorly nearly to the posterior margin of the gut loop but seldom beyond it. A small sac or protuberance (*r.c.*) is found on the left wall of the alimentary tract just dorsal to the base of the large caecum (Fig. 7). The duct of the circum-intestinal gland (*d.c.g.*) opens into the tip of this small sac, which could be considered merely a swelling of the proximal end of the duct. It is clear, however, that it is actually a projection of the alimentary tract. The swollen portion is stained reddish orange by Rose Bengal, like the alimentary tract, rather than purplish red like the duct. The relative positions of the small and large sacs indicate that they are the right and left caeca respectively.

The testis (*t.*) is about half the length of the left caecum and is situated on the right side of the ventral branch of the intestinal loop near its posterior margin. The vas deferens (*v.d.*) crosses the duct of the circum-intestinal gland on the left side and opens into the atrial cavity just in front of the point where the dorsal visceral muscles (*l.x.* and *r.x.*) from each side unite. These joined muscles project posteriorly into the center of the intestinal loop passing to the right of both the vas deferens and the duct of the circum-intestinal gland. The left visceral muscle (*l.x.'*) runs along the ventral side of the intestinal loop,
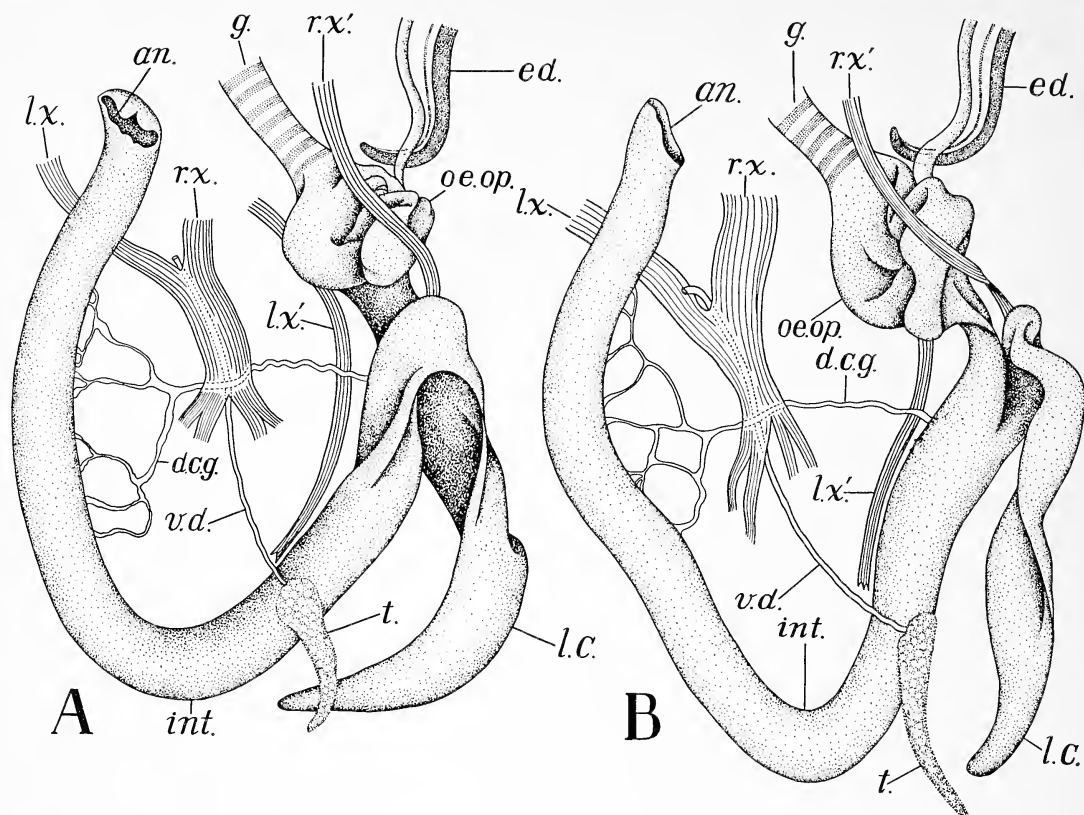
FIG. 6. A, *Cyclosalpa strongylenteron* Berner 1955, visceral region of the aggregate form, sinistral individual, from the right side. B, Same for dextral individual.

Abbreviations: *an.*, anus; *d.c.g.*, duct of the circum-intestinal gland; *ed.*, endostyle; *em.*, embryo; *g.*, gill; *ht.*, heart; *int.*, intestine; *l.c.*, left blind sac; *l.o.*, luminous organ; *l.x.*, left dorsal visceral muscle; *l.x'.*, left ventral visceral muscle; *oe.*, oesophagus; *r.c.*, right blind sac; *r.x.*, right dorsal visceral muscle; *r.x'.*, right ventral visceral muscle; *t.*, testis; *v.d.*, vas deferens.

crosses the duct of the circum-intestinal gland on the left side, and extends to near the base of the testis. The right visceral muscle (*r.x.'*) extends along the left side of the left caecum to a point near its posterobasal portion.

In the sinistral individuals the small right caecum is completely missing. The left caecum turns across the alimentary tract on the right side as shown in Figure 6A. The duct of the circum-intestinal gland opens at the base of the left caecum. Other structures are the same as in the dextral individuals.

The asymmetries found in the relation between the large (left) caecum and the small, or absent, right caecum, the arrangement of

the testis, vas deferens, duct of the circum-intestinal gland and the visceral muscles, are all of a primary character. The twist of the left caecum, shown in the sinistral individuals, may be considered to have been brought about by enatiomorphism.

The structure of the intestinal loop of the aggregate form of *Cyclosalpa bakeri* Ritter 1905 (Fig. 8) closely resembles that of the aggregate form of *C. strongylenteron*. It is U-shaped, with the anus (*an.*) opening on the same level as the oesophageal opening (*oe. op.*). The right caecum is absent in both the dextral and the sinistral individuals. In the dextral individuals the left caecum (*l.c.*) is attached ven-
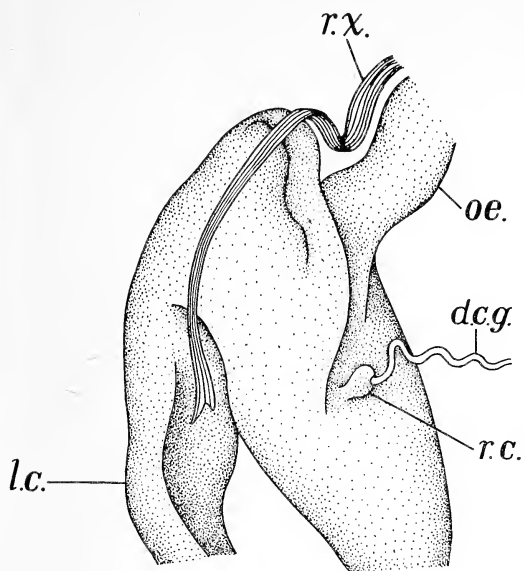
FIG. 7. *Cyclosalpa strongylenteron* Berner 1955, basal portion of left blind sac from left side.

trally about two thirds of the way down the lower branch of the intestinal loop. Its distal end reaches far beyond the posterior margin of the loop. In the sinistral individuals the caecum is twisted counterclockwise around the alimentary tract, as in the case of the sinistral individuals of *C. strongylenteron.* In the dextral individuals the duct of the circumintestinal gland (*d.c.g.*) opens into the intestine on the left side at the level of the anteriobasal portion of the caecum. In the sinistral individuals it opens into the base of the caecum itself.

The testis (*t.*) is held completely within a posterior protuberance projecting from the posterior portion of the intestinal loop. It is considerably longer than in *C. strongylenteron.* The vas deferens runs across the right side of the intestine, crosses the duct of the circumintestinal gland on the left side, and opens into the atrial cavity at a position far anterior to the anus.

The right visceral muscle (*r.x.*) runs down the right side of the intestinal loop to its posterior margin. The left visceral muscle (*l.x.*) projects deep into the posterior protuberance

with the testis. In the dextral individuals the caecum is superficially placed in the median plane and asymmetry can be found only in the arrangement of the vas deferens and the difference in length of the visceral muscles. Such asymmetries are all of a primary nature.

If the structure of the visceral regions of the aggregate forms of *C. bakeri, C. strongylenteron,* and *C. virgula* are compared, we may be able to say to which *C. strongylenteron* is more closely related. On this basis it occupies an intermediate position between *C. virgula,* which has the small right caecum in both the dextral and sinistral individuals, and *C. bakeri,* in which the right caecum is lacking in both individuals. If, however, the musculature is phylogenetically more important than the structure of the visceral portion of the body, the above hypothesis is untenable.

During the examination of *C. bakeri* two
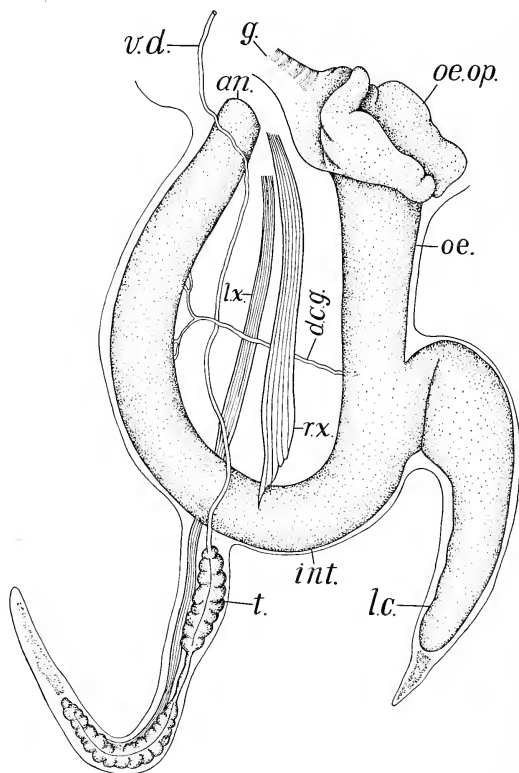
FIG. 8. *Cylosalpa bakeri* Ritter 1905, visceral portion of dextral individual, from right side.

individuals of the aggregate generation were found which appeared to have light organs (Fig. 9). The organs were situated mid-laterally, one on each side of the body between muscles II and III. This is the first report of possible light organs in the aggregate generation of *C. bakeri*.

SUMMARY

Two new species in the genus *Doliolina*, *D. obscura* and *D. separata*, have been described. The genus *Doliolina* has been subdivided into two groups. The first is the *Doliolina* perfecta, in which all the muscle bands form complete loops, the second the *Doliolina* imperfecta, in which the seventh muscle band is interrupted ventrally.

The presence of fingerlike protuberances on the stomach of *Doliopsoides horizoni* have been described. Specimens of *Doliolina undulata* in which the undulations of the testis are much reduced are described. This straightening of the testis appears to be associated with early maturity.

Doliolina intermedium is reported from the central and tropical Pacific Ocean. The specimens differ from those previously described in having a slightly longer testis and in the nearness of the ovary to muscle VII.

The structure of the intestinal region of *C. strongylenteron* and *C. bakeri* are reviewed. On the basis of the structure of this region *C. strongylenteron* is placed in a position intermediate between *C. bakeri* and *C. virgula*.

The presence of what appear to be light organs in the aggregate generation of *C. bakeri* is noted.

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FIG. 9. *Cyclosalpa bakeri*, a 12 mm. aggregate form showing placement of luminous organ. A, from right side; B, from left side.

A Review of the Labrid Fish Genus *Labroides*, with Descriptions of Two New Species and Notes on Ecology[1]

JOHN E. RANDALL

AN INDO-PACIFIC genus of small labrid fishes (wrasses), *Labroides* Bleeker, is here restricted to four species, two of which are described as new from islands of the tropical central Pacific. Underwater observations of all of the species have revealed the unusual food habit of removal of ectoparasites from other fishes. This is discussed for each species in the accounts following taxonomic considerations.

Günther (1862: 120) and Fowler (1949: 117) considered *Diproctacanthus xanthurus* Bleeker in the genus *Labroides*. I am in agreement with de Beaufort (1940: 19, 151, fig. 26) that the monotypic *Diproctacanthus* Bleeker is a valid genus. *D. xanthurus* lacks the characteristic bilobed lower lip of *Labroides* and has two instead of three anal spines.

Smith (1957: 100, 104) established a new genus, *Fowlerella*, for *Labroides bicolor*, principally on the basis of fewer lateral line scales than *dimidiatus*. In view of the similarity of *bicolor* to *dimidiatus* in other respects than number of scales, I refer *Fowlerella* to the synonymy of *Labroides*

Smith included *Labrus quadrilineatus* Rüppell (1835: 6, pl. 2, fig. 1) from the Red Sea with *dimidiatus* in the genus *Labroides* even though its scale counts would seem to ally it with *bicolor*. Actually *quadrilineatus* probably does not belong in *Labroides*, for this species has a completely scaled head (whereas in *Labroides* the head is naked except for suborbital, postorbital, and opercular regions), a slightly emarginate caudal fin, eight instead

of nine dorsal spines, and in Rüppell's moderately detailed description there is no mention of a bilobed condition of the lower lip. Fowler (1928: 331) (after Schmeltz) also placed *quadrilineatus* in *Labroides* and listed it from Samoa. I am dubious of this record. Possibly Schmeltz obtained the young of *Labrichthys cyanotaenia* Bleeker which have two lengthwise pale bands on the body (although these are lower on the body of *cyano-taenia* than they are on *quadrilineatus* and the more ventral band is not as distinct). *Labrichthys unilineata* (Guichenot) from Guam is probably a synonym of *Labrichthys cyanotaenia*, based on this juvenile color pattern.

Saville-Kent (1893: 308, col. pl. 16, figs. 4, 9) described two species of *Labroides*, *L. bicincta* and *L. auropinna*, after seeing them in coral pools of Lady Elliot Island reef in the Great Barrier Reef of Australia. He obtained no specimens, but preferred to "provisionally" give the fishes new names. Although the color drawings on which these names are based are crude, it seems very likely that the blue and black *L. bicincta* is a juvenile *L. dimidiatus*. Saville-Kent mentioned its "resemblance to the white and black banded *L. dimidiatus*, C. and V." Obviously he was not aware that the true life color of *L. dimidiatus* is blue and black. The figure of *L. auropinna*, a blue fish with yellow fins, fits no known species of *Labroides*. Until a more complete description with necessary meristic, measurement, and detailed descriptive data on the species is available, I prefer not to recognize this name. It is possible that *L. auropinna* is not a species of *Labroides*, and perhaps not even a labrid.

The genus *Labroides* is distinguished from other genera of the Labridae in having a small mouth with thick lips, the upper with a shallow median groove and the lower divided into two prominent, anteriorly projecting lobes. The inner surface of the lips has fleshy folds. There is a single pair of large, curved, canine teeth anteriorly in each jaw, the upper pair fitting inside the widely-spaced lower pair when the mouth is closed. There is a large, anteriorly directed, canine tooth at the extreme posterior part of the upper jaw, separated by a gap from anterior teeth. The remaining teeth are small, those in the lower jaw in several close-set rows between the canines and those in the upper jaw forming a large mass just behind the anterior canines, this mass with a marked indentation anteriorly in the mid-line. The body is compressed, its width contained about 2.5 to 3 times in the head length, and moderately elongate, its depth contained about 3.5 to 4 times in the standard length. The caudal fin is truncate or slightly rounded. The preopercle is entire, its margin smooth. The gill membranes are attached to the isthmus. The snout is pointed. The snout, entire dorsal surface of the head, chin, and throat are scaleless. The lateral line is continuous, and the lateral line scales number 28 or 52 to 54. Fin ray counts are as follows: D IX, 11 or 12; A III, 10; P 13 (uppermost two rays unbranched). The species are small, individual fish usually being less than 100 mm. in standard length.

KEY TO THE SPECIES OF LABROIDES

(Applicable primarily to adults;
see discussion below concerning juveniles)

1a. Lateral line scales 52 to 54; color light blue with a median lateral black band from snout to end of caudal fin (this band broadening as it passes posteriorly on body) (Indo-Pacific)................ ....**Labroides dimidiatus**

1b. Lateral line scales 28; color not as above (although a median lateral black band is often distinct anteriorly on body and on head)...........................2

2a. Snout long, diameter of eye contained 2.1 to 2.5 times in snout length; caudal peduncle and caudal fin pale with a prominent black crescent posteriorly in fin, the attenuate ends of which extend to margins of caudal peduncle (tropical Pacific) ....**Labroides bicolor**

2b. Snout not long, diameter of eye contained 1.5 to 1.9 times in snout length; caudal peduncle and caudal fin black with upper and lower edges of fin pale...........3

3a. Median lateral black band which extends posteriorly from snout continuous with black posterior half of body; no dusky streak on cheek below eye; pale edges of caudal fin magenta in life; maximum standard length in excess of 80 mm. (Hawaiian Islands).................. .....**Labroides phthirophagus**, n. sp.

3b. Median lateral black band which extends posteriorly from snout merges gradually to broad, pale-brown (dull-orange in life) area in center of body; a narrow dusky streak on cheek below eye running from chin to base of pectoral (may be faint in small adults); pale edges of caudal fin light lavender in life; maximum standard length about 60 mm. (Society Islands and Tuamotu Archipelago)........... ....**Labroides rubrolabiatus**, n. sp.

Juvenile specimens for all species are unavailable to me; however, all have been viewed underwater, frequently in the proximity of adults. Juveniles of all four species appear to have the same basic color pattern, namely black with a broad band of color along the back which extends and narrows on to snout. On *L. dimidiatus* and *L. rubrolabiatus* this band is brilliant deep blue (these species are readily separable by scale counts; see key above); on *L. bicolor* it is bright yellow; on *L. phthirophagus* it is bright purple.

Labroides dimidiatus
(Cuvier and Valenciennes)
Fig. 1

Labrus latovittatus Rüppell, (*non* Lacépède), 1835, Neue Wirbelth., Fische . . . , p. 2.
Cossyphus dimidiatus Cuvier and Valenciennes, 1839, Hist. Nat. des Poiss., vol. 13, p. 136.
Labroides paradiseus Bleeker, 1851, Natuurk. Tijdschr. v. Nederland. Indië, vol. 2, p. 249.
Labroides bicincta Saville-Kent, 1893, The Great Barrier Reef of Australia, p. 308, pl. 16, fig. 4.
Labroides caeruleo-lineatus Fowler, 1945, Acad. Nat. Sci. Phila., Proc., vol. 97, p. 65, fig. 7.

TYPE LOCALITY: Mauritius.

This blue and black species is the most common and widespread of the genus, ranging from Africa to the tropical Pacific (where it is recorded from most major island groups).

Labroides paradiseus Bleeker differs from *dimidiatus* in having a hooklike ventroanterior extension of the broad black band in the caudal fin. I have observed various degrees of intermediacy between typical *dimidiatus* and the *paradiseus* form, and I regard the latter as a color variety, as did Günther (1881: 243). In the Society Islands and Tuamotu Archipelago I have seen no specimens of the *paradiseus* variety, although collections are not extensive. In large collections from the Marshall Islands and the Philippines in the United States National Museum the *paradiseus* form predominates.

At Makatea and Takaroa in the Tuamotu Archipelago, and to a lesser extent at Tahiti and Moorea, another color variant was observed. Occasional adults have a dull red-orange region in the middle of the body below and adjacent to the median black band. In the Marquesas *L. dimidiatus* were seen with a red-orange area which was longer and occurred above as well as below the black band.

Barnard (1927: 749) described two color varieties of the species at Natal, East Africa, one with a dark stripe across the base of the pectoral fin and one without. He stated that the color of the species in Africa is blue or yellow with a black longitudinal band. Smith (1949: 291), also reporting on the species from East Africa, described the color as varying rapidly from light pink through straw yellow to dark blue, apparently at will and according to the emotional state of the fish. I have never seen *L. dimidiatus* in the Pacific pink or yellow instead of blue, nor have I observed any rapid color changes. With age there is a loss of brilliance and a lightening of the blue color. Below the median black band large adults are nearly white.

A juvenile specimen, 24 mm. in standard length, collected by the author in Tahiti, was colored in life as follows: black with a band of deep blue about a pupil diameter in width beginning at upper lip and passing backward through upper part of eye (lower edge of band at upper edge of pupil) on to nape, where it is nearly two pupil diameters in width, and thence on to back, where it gradually narrows until it terminates dorsally on caudal peduncle; the black middorsal region, which is bordered by a blue band on each side, is broadest on the head and narrows as
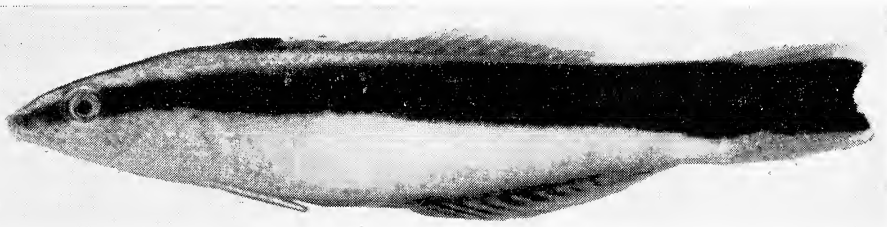
FIG. 1. *Labroides dimidiatus*, 83 mm., Society Islands. Caudal fin not expanded, hence emarginate appearance.

it passes posteriorly until it ends at rear of dorsal fin; head and thorax below level of lower edge of eye are pale; caudal fin black with narrow pale-violet edges; dorsal and anal fins dusky basally and hyaline distally, the dorsal blackish anteriorly, the anal darker posteriorly; paired fins pale.

Labroides caeruleo-lineatus Fowler (1945: 65, fig. 7) (1946: 159) is a young *L. dimidiatus*. The description was based on a 28 mm. specimen, and the figure clearly shows the typical juvenile color pattern as described above.

L. dimidiatus occurs most commonly in coral or coral-sand areas which are protected from wave action. Around atolls individuals are most often seen in lagoons rather than outside the peripheral reefs. I have observed them in water as shallow as 2 feet and as deep as 120 feet, but they appear to be more abundant in shallow water. Regan (1908: 230) has recorded the species from 34 fathoms in the Maldives.

Of this species de Beaufort (1940: 148) wrote, "In the aquarium of Amsterdam I observed that *Labroides dimidiatus* cleans the surrounding of the mouth and the gill openings of large fishes (Het Aquarium IV, 1936: 153) in the same way as has been observed by Beebe for the Atlantic species *Iridio bivittatus*." Smith (1949: 291) stated that *L. dimidiatus* "Feeds on minute organisms on rocks and has been observed to nibble over the mouth parts and gill covers of large Rock-cods." Doty and Morrison (1954: 24) observed what they termed an interesting association between a parrot fish and a fish which is undoubtedly *L. dimidiatus*.[2] The latter "cleans

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[2] These authors erroneously refer to this species as a blenny—probably because of the confusion that results from the similarity in color pattern of *L. dimidiatus* to the blenny *Aspidontus taeniatus* Quoy and Gaimard, a similarity so striking that Barnard (1927: 749) suggested that mimicry might be involved, with perhaps one or the other species being poisonous. R. W. Hiatt and D. W. Strasburg observed the resemblance at Arno Atoll in the Marshall Islands and suspected mimicry. Randall (1955b: 144), noting it in the Gilbert Islands, proposed that the blenny might be mimicking the labrid, since the latter might gain protection from predaceous fishes by virtue of its food habits.

off its larger companion's beaklike jaws, teeth and head area." They implied that this unusual association is limited to just these two species; however, I have observed (Figs. 2, 3, 5) *L. dimidiatus* picking at the heads, bodies, and fins of numerous species of reef fishes representing many different families, including the carangids and serranids, members of which habitually prey upon small reef fishes.

None of the above authors mentioned the removal of ectoparasites; the use of the term cleansing gives the connotation of removal of debris or particles of food.

The stomach contents of two specimens from the Gilbert Islands and three from the Marshall Islands consisted of calagoid copepods which are ectoparasitic on fishes; two more specimens from the Gilberts had eaten small isopods (also fish parasites) along with a few fish scales (Randall, 1955b: 144). Subsequently, a specimen, 72 mm. in standard length, from Hull Atoll, Phoenix Islands, was found to contain three caligid copepods

FIG. 2. A parrot fish, *Scarus* sp. (upper fish), and a surgeon fish, *Zebrasoma scopas* (lower fish), each being examined for ectoparasites by *Labroides dimidiatus*. Reproduced from 16 mm. movie film taken in the lagoon of Takaroa, Tuamotus.

FIG. 3. A pair of *Labroides dimidiatus* picking at the wrasse *Epibulis insidiator*. Reproduced from 16 mm. movie film taken in the lagoon of Takaroa, Tuamotus.

and three small fish scales in the stomach and the digested remains of numerous calagoid copepods in the intestine. A 71 mm. specimen from the Society Islands had two calagoids in the stomach and four calagoids and one larval gnathiid isopod in the intestine. One section of the intestine had a bit of soft bottom debris including a few fragments of algae. A 65 mm. specimen from the Society Islands had an empty stomach and the remains of 13 calagoid copepods and 1 lernaeid copepod in the intestine. A 24 mm. juvenile had eaten five small larval gnathiid isopods and three immature calagoid copepods. Nonparasitic crustaceans were not found in any of the specimens examined. The bottom debris in the one specimen may indicate occasional feeding on free-living forms, however, the species appears to be at least dominantly a feeder on crustacean ectoparasites of fishes.

Although Doty and Morrison (*op. cit.*) stated that parrot fish were feeding when the labrid cleansed them, host fishes generally not so oblivious to having their parasites removed. Usually the fishes display some distinctive behavior during the process. Often

they remain completely motionless in the water, although they may swim slowly. Usually their fins are fully erected (this may be associated with the high percentage of crustacean parasites which occur on the fins as compared with the rest of the body epidermis), and there may be a disorientation of the body to a position out of the vertical plane (i.e., tilted to one side) or with the anterior part of the body elevated. At times color changes are apparent. The black-hued surgeon fish *Acanthurus achilles* Shaw, for example, may become bright blue when picked over by *Labroides.*

Of all of the species of *Labroides*, *L. dimidiatus* is the least wary and will often swim up to a human observer, sculling along by pectoral fins alone in typical wrasse fashion, as if to investigate the possibility of human ectoparasites. I have experienced a picking at the hairs of my legs by this species and on one occasion a persistent and vigorous nipping at a small mole on my chest.

Randall (*op. cit.*) noted a peculiar mode of swimming often displayed by *L. dimidiatus* when near other fishes, describing it as an oscillation of the posterior part of the body during slow progression. Doty and Morrison wrote that this species swam "in an odd leaping fashion, somewhat like a finch in flight." I presume that this "dancing" about other fishes by this and other species of *Labroides*, coupled with their remarkable color, serves to enhance their recognition by the other fishes. Further, I noted in the Society Islands that *L. dimidiatus*, when near other fishes, often elevates its dorsal fin, especially anteriorly, such that the black forward part of the fin appears like a conspicuous black triangle.

On several occasions I have seen *Labroides dimidiatus* enter the buccal and gill cavities of larger fishes, ostensibly to remove parasites. Probably this occurs more often than these few observations suggest, for the proximity of a swimmer appears to frighten the host fishes sufficiently to preclude their entering

into this more complex symbiotic association. In Papetoai Bay, Moorea, at a depth of 20 feet, about a 200 mm. *Parupeneus trifasciatus* (Lacépède) approached an adult *L. dimidiatus*. As it neared the latter, it changed its color rapidly from light tan to mottled pink. The *Labroides* picked over the body and fins of this goatfish, moving anteriorly. When it reached the forward part of the head, the goatfish opened its mouth and the wrasse inserted more than half of its body into the mouth and remained there several seconds. Subsequently two adult goatfish of the species *Mulloidichthys samoensis* (Günther) interrupted the pair and received the attention of the *Labroides*. D. W. Strasburg has written that he made the same observation with *L. dimidiatus* and *P. trifasciatus* at Eniwetok Atoll in the Marshall Islands. In Teavenui Pass, Bora Bora, Society Islands, at a depth of about seven feet, I saw a 1240 mm. moray eel (*Gymnothorax javanicus* Bleeker) with its head and anterior third of its body projecting from beneath a coral ledge. It was being picked over by a *L. dimidiatus* about 50 mm. long. After about 30 seconds the wrasse devoted its attention to the eel's head, whereupon the latter opened its mouth widely, maintaining it in this position for about eight seconds while the labrid picked inside the upper and lower jaws and then disappeared back into the pharynx. A sharp lateral jerk of the eel's head preceded the departure of the wrasse. The eel was then speared to permit positive identification. A similar observation was made at Takaroa in the Tuamotus. The eel appeared to be the same species and the *L. dimidiatus* was a juvenile about 20 mm. in length. At Caroline Atoll (10° S., 150°14′ W.) I saw an adult *L. dimidiatus* slip the anterior third of its body into the gill cavity of the chaetodontid *Hemitaurichthys thompsoni* Fowler by way of the gill opening. The latter held its opercula open without respiring for several seconds to accommodate the labrid. In the Tuamotus individual *L. dimidiatus* were observed to enter the gill cavities of the wrasse

Epibulis insidiator (Pallas), the grouper *Variola louti* (Forskål), and the goatfish *Parupeneus barberinus* (Lacépède) via the gill openings.

Labroides dimidiatus are frequently seen in pairs. Also it has been noted that individual fish or pairs of fish appear to remain around the same small coral head or small section of a larger reef. The fish described above in association with *Parupeneus trifasciatus* is one of a pair which has been sighted in the same area over a period of six months. Other pairs or individual fish have been observed to be restricted to small areas.

If a parasite-feeding fish is resident to a small section of bottom and other fishes in the area are nonmigratory (probably true for the majority of coral reef fishes), its food supply would be insufficient, for it would be limited to the ectoparasites of fishes in its immediate surroundings. Therefore, it was not surprising to note that fishes come from beyond the range of vision to a *Labroides* site. A school of subadult *Mulloidichthys samoensis* was consistently seen to occupy a region of sandy bottom over 50 feet from the shore reef where the pair of *L. dimidiatus* mentioned above could be found. As I watched, small groups of about eight of the goatfish moved toward the *Labroides* site and remained in the area until they had been picked over; then they would return to their usual place. Their swimming back and forth from where the school congregated to where the *Labroides* were resident was not haphazard but directional, even though the water was not clear enough for me to see the reef from where the school was situated. Another species which swam to these two labrids from a locality previously known to me was a large adult *Abudefduf septemfasciatus* (Cuvier and Valenciennes), the only one of its size in the area. The rocks along the shore where it habitually hid are 45 feet from the labrid locale. *Caranx melampygus* Cuvier and Valenciennes, a foot or more in length, were other visitors which came to be "serviced" and left when the service had been finished. These fish are what

might be termed roving carnivores and appear to move over considerable distances. Yet they seemed to know the *Labroides* site, for they would come up to it from deeper water of the bay. At the atoll of Takaroa in the Tuamotus a four-foot moray eel (*Gymnothorax javanicus*) was seen to leave a hole in the coral, swim 15 feet over the bottom to a small coral head where a *Labroides dimidiatus* was located. There it was picked over the head and body by the labrid, after which it returned to the hole. Other fishes, such as *Ctenochaetus striatus* (Quoy and Gaimard), which were commonly seen being nibbled at by *L. dimidiatus*, could not be distinguished from one another or identified as having come from a certain area; nevertheless, it is expected that some means of marking many such fishes in the area, such as with different colored tags, would demonstrate that these fish are aware of the place where the *Labroides* can be found and swim there, perhaps under the stimulation of being irritated by ectoparasites. Individual *L. dimidiatus* are not wholly dependent on fishes bearing parasites coming directly to them. Often the species has been observed swimming over the reef for distances as great as 60 feet "servicing" fishes on the way. This was especially true in areas where the highly territorial damsel fish *Pomacentrus nigricans* (Lacépède) was common. As one damsel fish was being tended, another nearby would assume a stationary pose with fins erect and the *Labroides* would move on to the latter with little hesitation. For further discussion of the subject of restricted "home" sites of *Labroides*, as applicable to *L. phthirophagus*, see the account of this species.

The habit of feeding on ectoparasites is not unique to the genus *Labroides*, as might be surmised from the reference above to the labrid *Iridio* (= *Halichoeres*) *bivittatus* of the Atlantic. Longley (in Longley and Hildebrand, 1941: 129) reported that small porkfish, *Anisotremus virginicus* (Linnaeus), nibble and peck at the surfaces of larger fishes at Tortugas. I was fortunate to observe one individual of this species pecking at the body of the Nassau grouper, *Epinephelus striatus* (Bloch), in Florida, and can thus corroborate Longley's observation. In addition, I saw a juvenile of the pomacentrid *Microspathodon chrysurus* (Cuvier and Valenciennes) picking over the fins and body of an angel fish, *Pomacanthus arcuatus* (Linnaeus), which remained nearly motionless during the process. Also suspected of feeding on ectoparasites of fishes by Longley are the goby *Elacatinus oceanops* Jordan (p. 226) and the young of the labrid *Thalassoma bifasciatum* (Bloch) (p. 198). Of the former he wrote, "Wherever found, these small fish slip out from shelter, attach themselves by their ventral disks to other fishes, and 'creep' over them, presumably to look for parasites. As many as 6 have been seen together on a *Mycteroperca venenosa* about ¾ yard long. . . . The boldness of these tiny fish is almost incredible. They will creep over the teeth of the great *Pseudoscarus*, or enter the mouths of grunts and groupers and explore them with unhurried movements. . . . Their attentions usually continue until the larger fishes grow restless, start up abruptly, or move away and leave them, whereupon they return to their original stations."

Interestingly, the color of this goby is similar to that of *Labroides dimidiatus*. *E. oceanops* which I observed in Florida were blue with a black longitudinal band running from the snout through the lower part of the eye, broadening on the body, and ending on ventral half of caudal fin.

A recent paper by Eibl-Eibesfeldt (1955) is devoted in a large part to the detailed observation of the behavior of fishes which "cleanse" larger fishes. He observed the following species in the Caribbean in symbiotic association with larger fishes: *Elacatinus oceanops*, young *Thalassoma bifasciatum*, young *Anisotremus virginicus*, young *Bodianus rufus* (Linnaeus) (Labridae), and *Gramma hemichrysos* Mowbray (Pseudochromidae). He noted that the larger fishes do not merely accept the cleansing but invite it by taking special posi-

tions. Furthermore he observed that the larger fish seek out the stations of the "cleaners." He made the following observation of *Elacatinus oceanops* and *Epinephelus striatus*. As soon as the grouper came close to the coral where the gobies were located, the little fish swam immediately in his direction and started to clean his body. Sometimes the grouper lay on his side. He allowed the gobies to enter and leave the buccal cavity through his mouth and gill openings which he held rigidly open. After about 30 seconds he respired once or twice and then opened his mouth and elevated his gill covers again. When he wanted to leave, he made a signal by closing his mouth sharply, although not completely, and then opening it widely. At this signal the gobies came out. Before leaving the grouper shook his body. Even if frightened (as by a diver) he still took time to make the signal to the gobies. Of the small fishes listed above which cleanse larger fishes, only *Elacatinus oceanops* and young *Bodianus rufus* were seen to enter the buccal cavity of larger fishes. Large fish were never observed trying to catch any of the little fish. Eibl-Eibesfeldt suggests that it be ascertained whether the appetite of predaceous fishes is first appeased before they allow themselves to be picked over by the smaller fishes. No mention was made of the examination of stomach contents for ectoparasites by this author.

Eibl-Eibesfeldt has informed me in a letter that he has since observed "*Coris giofredi* Risso cleaning a *Crenilabris*" in the Mediterranean south of Naples.

Szidal and Nani (1951: 412) examined the stomach contents of a *Remora remora* (Linnaeus) from the coast of Argentina and found four parasitic copepods of the family Caligidae, three of them males of *Achteinus dentatus* Wilson and the other a female *Pandarus;* both forms are known to parasitize sharks.

Hubbs and Hubbs (1954: 194) stated that the embiotocid *Brachyistius frenatus* Gill and the labrid *Oxyjulis californica* (Günther) have at times been observed feeding on ectopara-

sites of other California fishes.

The food habit of removal of ectoparasites from other fishes represents a distinct biological niche. It is interesting to note how different species, often from totally different families, have filled this niche in different areas of the world; however, more of them are species of Labridae than of any other family. It should be added that primarily tropical and subtropical areas, where labrids are usually numerous, have been investigated.

In addition to fishes like *Labroides*, certain shrimps have been observed removing ectoparasites from fishes. In Papetoai Bay and the lagoon of Moorea at depths of about 70 feet the author watched a shrimp picking at fishes. The shrimp was identified as *Hippolysmata grabhami* by Dr. F. A. Chace, Jr. The adult shrimp are about 40 to 50 mm. in total body length, have a brilliant red band along the back which is bisected by a white middorsal line, and long white antennae and antennules. They were seen on the surface of isolated blocks of coral. When fish approached they waved their antennae and antennules as if to attract the fish. Among the fishes seen to enter into symbiotic association with this shrimp were: *Apogon exostigma* (Jordan and Starks), *Apogon* sp., *Anthias* sp., juvenile *Acanthurus mata* (Cuvier), and *Gymnothorax flavimarginata* (Rüppell). A shrimp climbed on to a two-foot specimen of the latter species and busily picked over the dorsal part of the eel's head.

Labroides bicolor Fowler and Bean
Fig. 4

Labroides bicolor Fowler and Bean, 1928, U. S. Natl. Mus., Bul. 100, vol. 8: 224, pl. 18.
TYPE LOCALITY: Port Maricaban, Philippine Islands.

Judging from the few locality records of the species (Philippines, Java (Hardenberg, 1936), Japan (Kamohara, 1952), the Gilbert Islands (Randall, 1955*b*), Aldabra, Indian Ocean (Smith, 1955)), *L. bicolor* would ap-
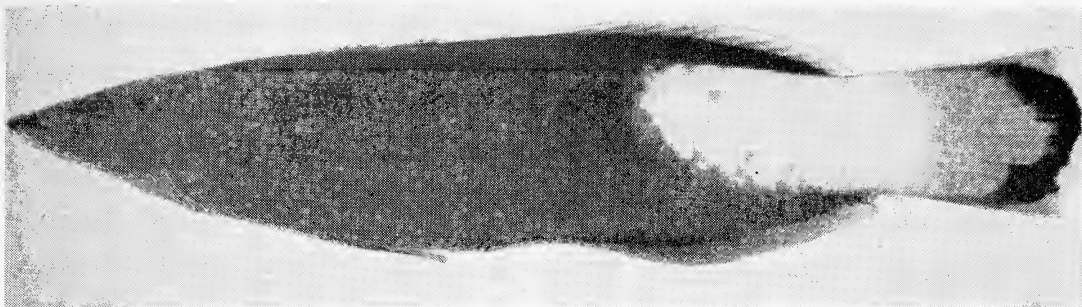
FIG. 4. *Labroides bicolor*, 81 mm., Gilbert Islands.

pear to be rare, although wide-ranging in the Indo-Pacific. I can attest to its rarity at Onotoa Atoll in the Gilbert Islands, where two months of field work resulted in the sighting of only two individuals. Subsequently in the Society Islands and Tuamotu Archipelago I have found the species surprisingly common for the genus. The two fish at Onotoa were observed in clear water beyond the windward reef of the atoll. Dr. Leonard P. Schultz of the United States National Museum has informed me that he will record the species from the northern Marshall Islands in volume II of *Fishes of the Marshall and Marianas Islands*. His specimens were taken on reefs exposed to severe wave action. In the Society Islands and Tuamotus, however, the species has rarely been observed outside of the barrier reefs but occurs more often around reefs in protected lagoon and bay areas. The apparent difference in habitat between this fish in the Gilbert and Marshall islands and the Society Islands may be a manifestation of possible subspecific differentiation. Further collections and observations are needed to elucidate the problem. Specimens from the Society Islands and Tuamotus have been sent to the United States National Museum and the Natural History Museum, Stanford University. *L. bicolor* was observed but not taken from the Marquesas Islands.

Although only adults were collected, the abundance of *L. bicolor* at the island of Moorea enabled me to perceive marked color changes which take place from the juvenile to the adult stage. In the following account, the color of juveniles is based on underwater observation. Juveniles as small as about 15 mm. in standard length have been observed. From this size to about 30 mm. the fish appear entirely black except for a brilliant yellow band along the back above the midlateral line of the body (this band confluent with one on other side dorsally on caudal peduncle and caudal fin) which extends on to head, including upper edge of eye and narrows as it terminates on snout. At a length of about 30 mm. the same general color obtains but the caudal fin and posterior part of caudal peduncle become pale yellow or almost white; subsequently, at the posterior part of the caudal fin, a trace of the black crescent so typical of adults appears. Then the yellow band along the back is replaced by light gray (the brilliant yellow color persisting longest on the head), and a light-gray area appears ventrally, thus restricting the black body color to a broad band along the middle of the body and head. Concomitant with the appearance of gray color is the development of the black crescent in the caudal fin. Anterior to the crescent a greenish tinge appears, replacing the pale-yellow color. Curiously, the next trend is a darkening of the light gray above and below the black band on the head and body and an intensification and enlargement of the yellow area posteriorly on the body. At about 60 mm. the yellow area is defined but scales anterior to the caudal peduncle have blackish centers. It is not until a standard length of nearly

75 mm. is reached that this large elliptical region is bright yellow, free or nearly so of scales with dusky centers. The green on the caudal fin also intensifies and blue appears posterior to the crescent and on the outer part of the dorsal and anal fins. On large fish (the species is the largest of the genus, attaining a standard length slightly in excess of 100 mm.) a suffusion of dark blue becomes apparent anteriorly.

A 98 mm. specimen speared in Moorea provided the following color description: body black except for a broad yellow area posteriorly, the forward end of which is rounded and reaches a vertical through base of fourth soft ray of dorsal fin; head dark blue and lacking the prominent black lateral band; lips dark blue, shading to light blue on inner surfaces; caudal fin with a subterminal black crescent, bright green anterior to and blue posterior to this marking; dorsal and anal fins black with broad light blue edges; pectorals hyaline; pelvics black.

This specimen and another 94 mm. one with the same color are males. On other individuals as large as blue-headed ones seen underwater the dark midlateral band is visible on the head and the deep-blue color is lacking, although the head and anterior part of the body above and below the band are dark grayish blue. The largest of the latter color variety collected in the Society Islands is 80 mm. in standard length, and it is a female. It is believed that others may consistently prove to be females too. At times one of each color variety are seen together as a pair. The above-mentioned color differences, if conclusively demonstrated to be sexual, are slight compared to the degree of sexual dichromatism known in some of the Labridae (Randall, 1955a).

On numerous occasions in the Society Islands and Tuamotus individuals of this species, both juvenile and adult, have been observed picking at the bodies, heads, and fins of other fishes. The contents of the gut of eight specimens, 60 to 98 mm. in standard

length, have been examined. Four were empty save for a mucuslike substance and, in the case of two of the specimens, tiny digenetic flukes in the intestine, which were probably internal parasites of these fish. A 69 mm. specimen had two calagoid copepods and one fish scale in the stomach; 65 and 80 mm. specimens were empty except for a few fish scales in the stomach and intestine. The stomach of a 60 mm. specimen was empty, but three small larval isopods of the family Gnathiidae (larvae of this family consist exclusively of fish parasites) were found in the intestine.

The presence of fish scales in the gut is comprehensible when the stout, curved, canine teeth and the vigor with which the little labrids nip the host fishes are considered. A medium-sized *L. bicolor* was seen to actually lift a piece of skin of an adult puffer, *Arothron meleagris* Bloch and Schneider, into a pronounced peak in its apparent effort to dislodge an ectoparasite.

The host fishes do not always tolerate such ardent pecking. Often they move their bodies sharply or swim away when the pecking becomes vigorous.

Adult *L. bicolor* do not display the oscillatory swimming movement as previously described for *L. dimidiatus*. The brilliant yellow and black young do, however. A further distinction between the behavior of young and adults lies in the tendency of the former to remain in a very restricted region, frequently a small cave or under a ledge. Adults are almost constantly on the move and appear to cover a larger area than other species of *Labroides*. Still, they seem to remain in the same general region. In addition to seeing what appeared to be the same individuals day after day at a certain reef, several which were wounded with a spear and could be positively identified were repeatedly sighted at approximately the same place.

As might be surmised from the above, adults of this species are more prone to seek out fishes from which to remove parasites

than the other species of the genus. They have been observed to follow individual fishes closely for 30 feet or more, frequently making contact with the dorsal fin or the dorsal part of the body of these fishes.

I have never observed *L. bicolor* enter the mouth or gill cavities of larger fishes as has been observed for *L. dimidiatus*, *L. phthirophagus*, and *L. rubrolabiatus*. *L. bicolor* is noticeably shyer than the other species, however, and individual fish usually swim away as a swimmer approaches; thus it is possible that such behavior occurs.

The three species of *Labroides* which are found in the Society Islands, Tuamotus, and Marquesas, *L. dimidiatus*, *L. bicolor*, and *L. rubrolabiatus*, are frequently seen near one another and rarely exhibit territoriality. On one occasion I observed all three together around a single small coral head. At Takaroa in the Tuamotus *L. dimidiatus* and *L. rubrolabiatus* were both seen to pick at the body of the parrot fish, *Scarus harid* Forskål, at the same time. In Moorea a five-foot moray eel of the species *Gymnothorax javanicus* was observed lying nearly motionless entirely in the open beside a small head of coral and being picked over simultaneously by two adult *Labroides*, one *L. dimidiatus* and the other *L. bicolor*. Until the small labrids were seen, the eel's position was perplexing, for morays are rarely seen free from their holes in the coral during the day unless in rapid transit from one hole to another. *L. dimidiatus* has thrice been observed to peck briefly at the bodies of adult *L. bicolor;* twice the *dimidiatus* were of about equal size as the *bicolor* (Fig. 5), and the remaining time definitely smaller.

Generally, individuals of the species of *Labroides* tend fishes larger than themselves, juveniles "taking care" of the smaller reef fishes. It is by no means rare, however, to see species of *Labroides* picking at fishes smaller than themselves. Conversely, tiny juveniles have been frequently seen busily working over the surface of fishes ten times or more their size. Several times *L. dimidiatus* 20 mm.

FIG. 5. *Labroides bicolor*, (on right) being "serviced" by *L. dimidiatus*. Reproduced from 16 mm. movie film taken in the lagoon of Takaroa, Tuamotus.

or less in standard length have been seen in association with adult groupers (*Cephalopholis argus* Bloch and Schneider) 200 to 300 mm. in standard length and *L. bicolor* of about the same small size with full-grown squirrel fishes (*Myripristis* spp.).

At Takaroa an adult *L. bicolor* was observed to swim after a six-foot shark of the species *Triaenodon obesus* (Rüppell) and to make a few hasty pecks at the dorsal part of the body.

Labroides phthirophagus, new species
Pl. 1A

HOLOTYPE: U. S. Natl. Mus. No. 164466, a male specimen, 68.0 mm. in standard length and 84.0 mm. in total length, collected by J. Randall with a spear in 7 feet of water, about 100 yards offshore from the Waikiki branch of the Hawaii Marine Laboratory, Honolulu, Territory of Hawaii, on March 1, 1955.

PARATYPES: U. S. Natl. Mus. No. 164469, 69.0 mm. in standard length, collected by J. Randall with a spear in 5 feet of water in

Kealakekua Bay, Hawaii, on June 15, 1954; U. S. Natl. Mus. No. 164467, 83.5 mm. in standard length, collected with rotenone by W. Gosline and class at Diamond Head, Oahu, on Dec. 22, 1951; U. S. Natl. Mus. No. 164468, 18.8 mm. in standard length, collected with rotenone by W. Gosline and class at Diamond Head, Oahu, on Dec. 23, 1953; Stanford Univ. Mus. No. SU48445, 2 specimens, 64.5 and 69.0 mm. in standard length, collected by J. Randall with a spear in 18 feet of water at Waianae, Oahu, on Oct. 14, 1955; British Mus. No. 1955.12.12.1, 60.0 mm. in standard length, collected by J. Randall with a spear in 35 feet of water at Manana Island (Rabbit Island), Oahu, on Sept. 29, 1955.

In addition to the above, there is a series of 12 specimens, 19 to 76 mm. in standard length, in the collection of the University of Hawaii.

DESCRIPTION: Based on the holotype and the smallest (18.8 mm. in standard length, 23.2 mm. in total length) and the largest (83.5 mm. in standard length, 103 mm. in total length) paratypes. Counts and measurements are recorded for the holotype, followed in parentheses by data for the small and large paratypes, respectively. When counts of the two paratypes are the same as the holotype, only a single number is given.

Dorsal fin rays IX, 11; anal fin rays III, 10; pectoral fin rays 13 (the uppermost rudimentary, the next unbranched); pelvic fin rays I, 5; principal caudal rays 14. Lateral line scales 28, the last slightly enlarged and with a prominent lateral line tube; lateral line partially interrupted in adults (the lateral line in the 20th and 21st scales, the two which contain that part of the line which angles sharply downward at the level of the posterior part of the dorsal fin, is poorly developed; no degeneration in the lateral line at this location is apparent in the 18.8 mm. juvenile specimen, however). Scale rows above lateral line to base of first soft dorsal rays 3; scale rows below lateral line to base of first anal soft rays 8; median predorsal scales 8 (9 or 10 in

large paratype and none in the juvenile specimen). Snout, chin, throat, and dorsal part of head naked. Gill rakers (including rudiments) on first gill arch 14 (large paratype only).

Head length 2.77 (2.22–2.80); depth of body 3.64 (3.69–3.50); snout to anus 1.59 (1.60–1.61); snout to origin of pelvic fins 2.72 (2.77–2.74); snout to origin of dorsal fin 2.86 (2.51–2.95); length of dorsal fin base 2.06 (2.09–1.95); length of anal fin base 3.54 (3.76–3.76)—all in standard length.

Width of body at gill opening 2.34 (3.12–2.64); least depth of caudal peduncle 1.92 (2.62–2.04); snout length 3.46 (3.73–3.21); diameter of eye 5.16 (4.20–5.97); width of interorbital 3.64 (4.65–3.59); length of pectoral fin 1.61 (1.87–1.65); length of pelvic fin 2.31 (2.80–2.29); width of mouth (rictus to rictus) 5.39 (5.25–5.98); mid-center of upper lip to rictus 6.13 (5.80–6.15)—all in head length.

Dorsal spines progressively longer, the ninth 3.50 (3.90–3.59) in head length; first dorsal soft ray 2.45 (2.89–2.54) in head length; second anal spine twice as long as first; third anal spine twice as long as second; third anal spine 3.36 (3.72–3.32) in head length; first anal soft ray 2.29 (2.80–2.56) in head length. Caudal fin slightly rounded.

A pair of large curved canine teeth in upper jaw, each nearly a pupil diameter in length and separated by a distance about equal to the diameter of one of the teeth at the base. A similar pair of canine teeth in lower jaw, lateral to but nearly touching upper teeth when mouth is closed. Remaining teeth small, except one at angle of jaw, those at the symphysis of upper jaw in numerous close-set rows, forming a semicircular mass between the two canine teeth.

Color in alcohol: posterior half of body and caudal fin black except upper and lower edges of caudal fin and dorsal edge of caudal peduncle which are white (magenta in life); anterior half of body light tan (yellow in life) with a median dorsal black band (beginning in a small spot on median upper portion of

upper lip) and a median lateral black band running posteriorly from lower corner of upper lip and tips of lobes of lower lip through eye to merge with black posterior part of body; dorsal and anal fins pale (light blue in life), except for basal part of spinous portion of dorsal fin which is black (this color continuous with that of median dorsal black band) and a narrow horizontal dark line extending from ends of last few dorsal spines posteriorly into the anterior half of the soft portion of the fin about three-fourths the distance from the base of the fin; paired fins pale. The body of the 18.8 mm. juvenile specimen is black except for a broad light-brown band along the back, this band continuing on to top of caudal fin; the remainder of the caudal fin is black like the body except for lower distal corner which is pale; the head is brown with median dorsal and median lateral black bands. In life the band along the dorsal part of the head and body is bright purple. No yellow color is visible on juveniles. The first indication of the yellow coloration is a suffusion of tan over the head and anterior part of the body. This occurs at a length of about 50 mm. (based on estimates of the size of individuals seen underwater).

Labroides phthirophagus is known only from the Hawaiian Islands, where it is a common species. That it escaped being described in Jordan and Evermann's time is probably due mainly to its small size. It is too small to be caught in the usual fish traps or hook and line. An indication of its abundance is its listing [as *L. dimidiatus* by Brock (1954: 307)] among the species consistently tabulated in his underwater transects of Hawaiian reef fishes.

The record of *Labroides dimidiatus* by Günther (1881: 243) from the Hawaiian Islands is open to question. It seems possible that he might have obtained *L. phthirophagus* and confused it with *L. dimidiatus*, for the latter, if it occurs in Hawaii at all, is certainly rare. On one occasion I observed a small individual of what I believe to be this species

underwater in Kaneohe Bay, Oahu.

Although generally seen around rock or coral, *Labroides phthirophagus* does not appear restricted to any special habitat. I have observed it in clear water of high coral cover such as Kealakekua Bay and turbid, at times brackish, water lacking living coral such as the Ala Wai Yacht Basin, Honolulu (it is, however, uncommon in the latter area). It occurs in water at least as shallow as 2 feet and has been seen at a depth as great as 90 feet (it may occur deeper—there have been few observations beyond 90 feet).

L. phthirophagus (Greek: *phtheiros*, louse; *phagous*, eat) is named for its habit of feeding on external parasites of fishes.

The food habits of *L. phthirophagus* were suspected from observation of its picking at the surface of other fishes (Fig. 6) and from the knowledge that *L. dimidiatus* feeds on parasitic copepods and isopods from fishes.

In order to obtain more positive evidence of such a mode of feeding, the contents of the alimentary tract of 11 specimens of *L. phthirophagus* in the collection of the University of Hawaii were examined. None of the specimens represent type material. They were
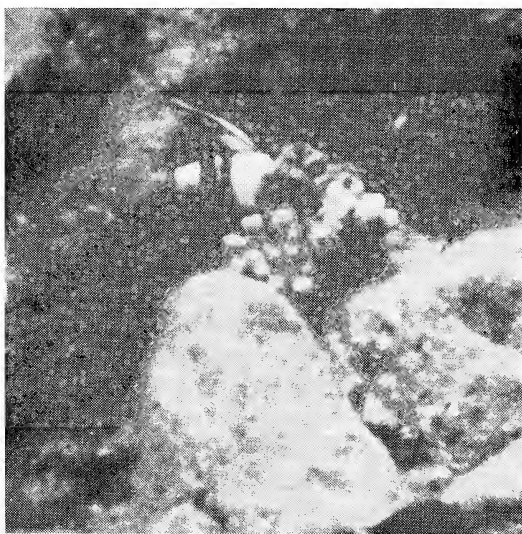
FIG. 6. *Labroides phthirophagus* picking at the body of a goatfish, *Parupeneus multifasciatus*. Reproduced from 16 mm. movie film taken off Manana Island, Oahu.

collected with rotenone from the islands of Oahu, Molokai, Maui, and Hawaii. The results of the examination of the gut contents of these specimens are given below in Table 1, along with the date of collection and the standard length and sex of the specimens.

It seems evident from Table 1 that *L. phthirophagus* feeds primarily on parasitic copepods and isopods from fishes. The fish scales and fragment of fin membrane were probably accidentally ingested in the process of picking at parasites. The cyclopoid copepods (lichomolgids and harpacticoids) do not appear parasitic. They are tiny, and when present in the gut, they are usually numerous, suggesting that they may have been encountered by the labrid in a convenient concentration. That parasites are not the sole diet was further shown by the following observation in Kealakekua Bay, Hawaii. Several nests of the pomacentrid fish *Abudefduf abdominalis* (Quoy and Gaimard) were seen at a depth of 90 feet. When the guarding adult was frightened from one of the nests, a number of other fishes commenced to feed avidly on the eggs, among them an adult *L. phthirophagus*.

Like *Labroides dimidiatus* and *L. bicolor*, *L. phthirophagus* is nonspecific in the fishes which it "services." Among the groups of reef fishes commonly seen participating in symbiotic relationship with *L. phthirophagus* are acanthurids, pomacentrids, scarids, labrids, chaetodontids, mullids, and plectognaths.

Species of *Caranx* are not abundant in the Hawaiian Islands and none were observed in association with *L. phthirophagus*. Only one carangid, *Decapterus pinnulatus* (Eydoux and Souleyet), was seen to associate with the labrid. As a school of this species swam over the bottom off Waikiki, Oahu, a single *Labroides phthirophagus* swam upward to the school. One of the carangids left the school, swam slowly in a small circle, and quivered slightly as the *Labroides* pecked at its body surface.

On one occasion when a *Labroides* was tending a large butterfly fish of the species *Chaetodon lunula* (Lacépède), the latter ceased its gill movements and elevated its operculum. The labrid inserted the anterior half of its body into the gill cavity through the gill opening, where, for several seconds, it presumably searched for parasites.[3] The same behavior was observed for the goatfish *Parupeneus prophyreus* (Jenkins). With the use of self-contained breathing apparatus in clear water of about 40 feet in depth off Manana Island (Rabbit Island), Oahu, an individual *Labroides phthirophagus* was seen to enter the buccal cavity of an adult goatfish, *Mulloidichthys samoensis* (Günther), by way of the mouth, such that the majority of the body of the labrid was lost from view. About five seconds elapsed before the *Labroides* emerged.

Frequently the act of removal of parasites by *Labroides phthirophagus* occurs beneath a ledge or in an interstice in the reef, making observation difficult. Furthermore, the approach of a swimmer usually interrupts the proceedings. For these reasons an effort was made to bring living specimens of *Labroides* into large aquaria where it was hoped detailed observations of behavior could be made.

A total of three were caught underwater with dip nets in Kaneohe Bay and brought to the Honolulu Aquarium. None were maintained in the aquaria long enough for normal feeding behavior to manifest itself; however the reactions of the resident fishes of the aquaria bear mentioning. When placed in a tank containing many moorish idols (*Zanclus cornutus* (Linnaeus)), one balistid (*Rhinecanthus aculeatus* (Linnaeus)), and an unidentified large scorpaenid, the *Labroides* swam about the aquarium, paying little attention to the other fishes. It was evident, however, that the

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[3] I suspect that the parasites removed from the gill cavity by *Labroides* are still principally calagoid copepods. In a study of the parasites of the surgeon fish *Acanthurus triostegus sandvicensis* Streets (MS data), I observed individuals of the most common parasitic copepod of this fish, an undescribed species of *Lepeophtheirus*, freely enter and leave the gill and buccal cavities of the fish. The genus *Lepeophtheirus* is the most abundant of the calagoids listed in Table 1.

TABLE 1

GUT CONTENTS OF SPECIMENS OF *Labroides phthirophagus*

DATE COLLECTED	STANDARD LENGTH (MM.)	SEX	GUT CONTENTS
Apr. 10, '50..........	58	F(ripe)	2 calagoid copepods, 4 larval gnathiid isopods, fish scales
Sept. 21, '51.........	53	F	4 calagoid copepods, 25 harpacticoid copepods*
May 11, '52.........	60	F	3 calagoid copepods, 1 lernaeid copepod†, 88 lichomolgid copepods‡
Dec. 31, '52.........	42	M	2 calagoid copepods, 1 lernaeid copepod†
	49	F	14 calagoid copepods, 1 lernaeid copepod†, 4 larval gnathiid isopods
	55	F	10 calagoid copepods, 1 lernaeid copepod†, 6 larval gnathiid isopods, fragment of fin membrane
	76	M	2 calagoid copepods, 14 digenetic trematodes§
Jan. 21, '53..........	39	F?	1 calagoid copepod, 8 larval gnathiid isopods
June 19, '53.........	60	F	1 calagoid copepod, 19 harpacticoid copepods*
July 25, '55..........	58	F	6 calagoid copepods, fish scales
Aug. 7, '55..........	63	F	14 calagoid copepods

* *Tisbe* sp.; most species are free-living but at least one is commensal (in a pelecypod).
† *Peniculus* sp., generally attached to fins.
‡ Many members of this family of cyclopoid copepods live commensally with tunicates, pelecypods, flatworms, etc.; however, according to Dr. Paul L. Illg, this species of copepod does not fit well into any genus so far proposed. Although no lichomolgid has turned up as parasitic on a vertebrate, this one is sufficiently distinctive anatomically (the arrangement of the maxillary suggests its use as a substitute masticatory appendage) that it might have developed a divergent feeding mechanism.
§ Undigested, probably a gut parasite of the *Labroides*.

moorish idols and the trigger fish were immediately aware of the new arrival, for they reacted as in the normal environment. As the *Labroides* swam past individual fish, many were observed to cease swimming, and occasional moorish idols stopped their respiratory movements and raised their gill covers. The following morning the *Labroides* could not be found in the aquarium.

The second *Labroides* was added to a tank containing two parrot fishes (*Scarus* sp.) about 250 mm. in length and seven surgeon fishes (*Acanthurus* spp.). Again the *Labroides* paid little heed to the other fishes, but they reacted characteristically. The surgeon fishes swam about nervously in a restricted area of the tank. The behavior of the parrot fish was almost ludicrous. They followed the *Labroides* around the aquarium, stopping occasionally to literally stand on their tails, waggle their pectoral fins, and seemingly to ogle the labrid, as if to entreat it to perform the expected services. The parrot fishes and surgeon fishes were recognized as ones which had been in the aquarium at least several months.

This poses a question which is as yet unanswered. Do these fishes learn the role of *Labroides* through experience or is their behavior innate? The answer could be provided through observation of *Labroides phthirophagus* with aquarium-reared fishes or with fishes taken from an area where species of *Labroides* are known not to occur. If learned through experience, how long is the capacity for symbiotic association retained?

The second *Labroides* was left overnight in the aquarium, and it also was gone the next day. It is not known whether this and the first *Labroides* which disappeared were eaten by fish or whether they escaped down the drains (which, it was later noted, were not screened).

The third *Labroides* was placed in an aquarium containing only adult wrasses of many species. It was immediately chased about the tank by several individuals of different species and ultimately eaten by one of them. This was totally unexpected, for various wrasses were among the fishes which were observed being serviced by *Labroides phthirophagus* in the reef environment. The immediate

pursuit of the *Labroides* in the aquarium suggests that the wrasses might have been conditioned to rapid seizure of food items added to the surface of the tank, and that this reaction may have superseded the one which would occur in the normal habitat.

When in the proximity of other fishes, *Labroides phthirophagus* exhibits the same unusual oscillatory mode of swimming as seen in *L. dimidiatus*, although not as commonly.

As previously mentioned, the act of removal of ectoparasites by *L. phthirophagus* frequently takes place in a region of cover such as beneath a ledge. Repeated observations of one such ledge at Manana Island, Oahu, revealed that a pair of this species of *Labroides* could invariably be found at or near this site. These observations continued for a period of over three years. Other pairs or groups of three fish were similarly checked over long periods of time at the following locations: Waikiki, Kaneohe Bay, Hanauma Bay, and Kealakekua Bay, Hawaii. I conclude from these and lesser observations that adult *L. phthirophagus* tend to remain in a restricted area of the reef.

As with *Labroides dimidiatus*, it is believed that fishes seek out the area where *Labroides phthirophagus* occur in order to have their parasites removed. The first evidence that fishes might come to a *Labroides* site from beyond the immediate vicinity was the sighting at Manana Island of an adult manini, *Acanthurus triostegus sandvicensis* Streets, swimming from at least 40 feet away direct to the *Labroides* ledge where it stopped and erected its fins. As one of the *Labroides* swam up to this fish, the latter was speared and taken ashore. Macroscopic examination revealed the presence of three calagoid copepods. Seemingly purposeful swimming by other fishes to *Labroides* areas has been observed. Generally there is a concentration of reef fishes around a *Labroides* site. I have on several occasions located such a site by first noting a greater density of reef fishes in a restricted area than could be explained by any other reason.

Labroides sites are usually well separated from one another. This first became evident around the patch reefs in Kaneohe Bay. *Labroides phthirophagus* is generally found at a depth of about 5 to 20 feet at the steep margins of these reefs rather than their shallow, truncate tops. The spacing between sites, at times remarkably regular, is now linear and more readily perceived by an observer swimming around such a reef.

Although occurring singly or in groups of as many as five individuals, *Labroides phthirophagus* is most commonly seen in pairs. Often groups of three or more contain one or more juveniles in the company of a pair of adults. When a pair of adults is seen, it is natural to expect that one would be a male and the other a female. There is some evidence that this is the case. Of the four specimens shown in Table 1 which were collected at a poison station on December 31, 1952, two are males and two are females. One of the two paratypes which were speared on October 14, 1955, at Waianae, Oahu, is a ripe female (standard length 64 mm.; length of ovary *in situ* 12 mm.) and the other appears to be a male. These two fishes were found together and were the only two seen in the area surveyed.

Labroides rubrolabiatus, new species
Pl. 1 B

HOLOTYPE: U. S. Natl. Mus. No. 164603, a female specimen, 54 mm. in standard length and 66.5 mm. in total length, collected by J. Randall with rotenone in the lagoon at a depth of 20 feet next to a large coral head about 100 feet from shore one-fourth of a mile east of the entrance to Papetoai Bay, Moorea, Society Islands, on May 3, 1956.

PARATYPES: U. S. Natl. Mus. No. 164604, a female specimen, 51 mm. in standard length, collected by J. Randall with a spear 30 feet off the lee reef near the boat entrance of Caroline Atoll (10° S. 150° 14′ W.) at a depth of about 15 feet on February 12, 1956; Stanford Univ.
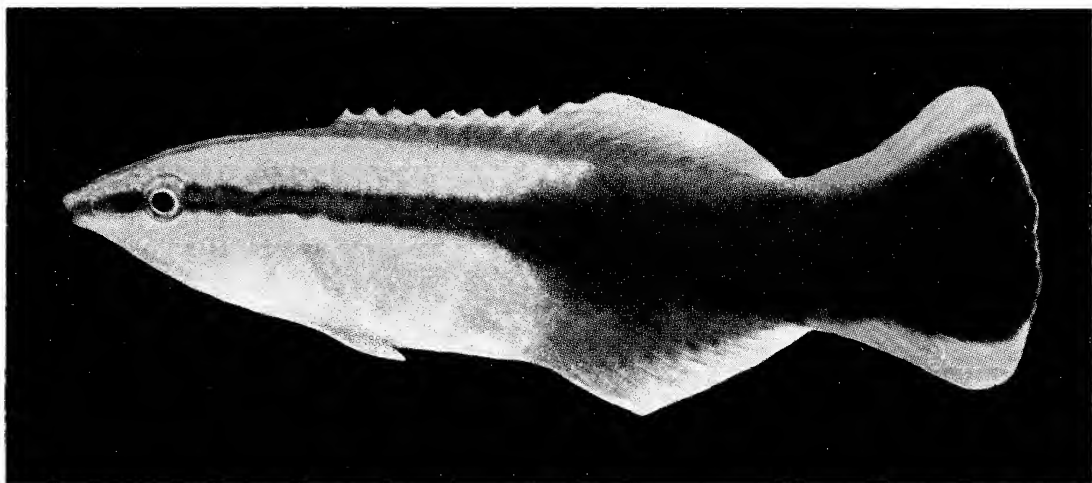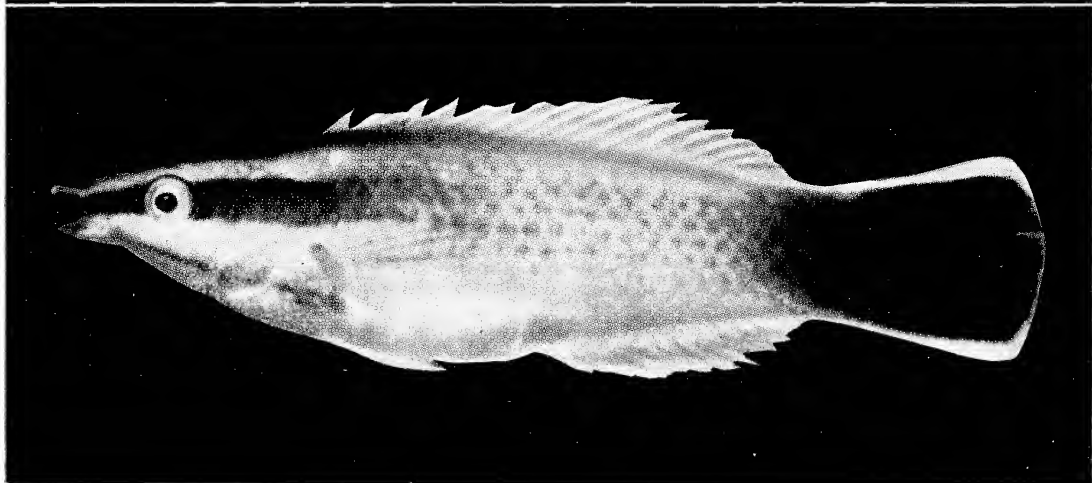
Plate 1
A. *Labroides phthirophagus*. Holotype, Oahu, Hawaiian Islands. Standard length, 68 mm.
B. *Labroides rubrolabiatus*. Holotype, Moorea, Society Islands. Standard length, 54 mm.

Mus. No. 48871, a female specimen, 48 mm. in standard length, collected by J. Randall with a spear in the Moorea lagoon just east of Tareu pass at a depth of 8 feet on May 22, 1956 (specimen was picking on the body of a female *Scarus sordidus* Forskål when speared); British Mus. No. 1956.8.14.1, a female specimen with mature gonad, 45 mm. in standard length, collected with a spear by J. Randall within 75 feet of the locality of the May 22 specimen at a depth of about 10 feet on March 29, 1956.

Two more specimens collected by the author, a male 46.5 mm. in standard length, from a depth of 7 feet in the Moorea lagoon near the entrance to Papetoai Bay on July 1, 1956, and a 54.5 mm. female from 15 feet in the pass at Takaroa, Tuamotu Archipelago, Nov. 9, 1956, have been placed in the collection of the University of Hawaii. Both specimens were speared, the former as it was picking at the dorsal fin of *Zebrasoma scopas* (Cuvier). No external differences could be ascertained between the one male specimen and the female specimens.

Some proportional measurements of the paratypes were difficult to make because of injury from spears.

DESCRIPTION: Based on the holotype and the smallest (45 mm. in standard length, 55.3 mm. in total length) and the largest (51 mm. in standard length, 62.5 mm. in total length) paratypes. Measurements are recorded for the holotype, followed in parentheses by data for the small and large paratypes, respectively. Meristic data are the same for the holotype and paratypes (with the possible exception of median predorsal scales which are obscure and difficult to count), hence only a single number is given for each count.

Dorsal fin rays IX, 11; anal fin rays III, 10; pectoral fin rays 13 (the uppermost rudimentary, the next unbranched); pelvic fin rays I, 5; principal caudal rays 14. Lateral line scales 28, the last enlarged and bearing a prominent lateral line tube (scales extend posterior to lateral line nearly half the remaining length of caudal fin); scale rows above lateral line to base of first soft dorsal rays 3 (the upper row extending on to base of dorsal fin); scale rows below lateral line to base of first anal soft rays 8 (two additional rows of moderately large scales on base of anal fin at this point); median predorsal scales 8 or 9; snout, chin, throat, and dorsal part of head naked. Gill rakers (including rudiments) on first gill arch of 48 mm. paratype 15.

Head length 2.78 (2.67–2.77); depth of body 3.48 (3.50–3.69); snout to anus 1.66 (1.70–1.69); snout to origin of pelvic fins 2.70 (2.59–2.66); snout to origin of dorsal fin 2.92 (2.74–2.91); length of dorsal fin base 1.99 (2.08–2.07); length of anal fin base 3.60 (3.89–3.90)—all in standard length.

Width of body at gill opening 2.70 (2.81–2.75); least depth of caudal peduncle 2.16 (2.33–2.32); snout length 2.85 (2.91–2.87); diameter of eye 5.11 (4.82–4.98); width of interorbital 3.81 (4.02–3.88); length of pectoral fin 1.50 (1.53 and 1.53); length of pelvic fin 1.96 (1.96–1.94)—all in head length.

First dorsal spine 8.64 (9.62–9.20) in head length; dorsal spines progressively longer (filaments of interspinous membranes extend beyond spine tips), the ninth 3.40 (3.75–3.58) in head length; first dorsal soft ray 2.43 (2.42–2.52) in head length; first anal spine nearly half as long as second; second anal spine about two-thirds as long as third; third anal spine 3.63 (3.47–3.57) in head length; first anal soft ray 2.18 (2.00–2.11) in head length. Caudal fin slightly rounded.

Width of mouth (rictus to rictus) equal to eye diameter. Center of upper lip to rictus about 5 in length of head. Distance between lobes of lower lip about one-third diameter of eye.

A pair of curved canine teeth (the uppers more curved than the lowers) anteriorly in each jaw, about one-fourth eye diameter in length. Upper canines fit inside lowers when jaws are closed (upper and lower canines on one side separated by a distance slightly less than diameter of base of one of the teeth). A

large semicircular mass of fused teeth in center of upper jaw just posterior to upper canines. This mass is as long as the upper canines with which it is in contact basally. It is indented anterocentrally. An inconspicuous band of small teeth may be seen anteriorly in the lower jaw. A canine tooth at angle of jaw.

Color in alcohol of Moorea specimens: light greenish brown, shading anteriorly on head to light bluish gray, with a black band running from mouth through eye on to body; on the body the band broadens as it passes posteriorly and becomes progressively indistinct until, in the median part of the body beyond the tip of the outstretched pectoral fin, it is barely discernible or absent; posteriorly it reappears, becoming black on caudal peduncle and caudal fin (which is completely black except for upper and lower edges and the posterior rounded corners which are white); a broad black middorsal band runs posteriorly from tip of snout and gradually lightens until it disappears at rear base of spinous portion of dorsal fin; a diagonal dusky streak from chin across cheek below eye to lower base of pectoral fin (obscure in 45 mm. paratype); spinous portion of dorsal fin dusky basally, pale distally; anal fin and soft portion of dorsal fin pale with a dark horizontal streak anteriorly located about two-thirds the distance from base to margin of fins; paired fins pale except for dark edges of pectoral fin rays.

The following color note from life was made of the holotype: body from region of end of pectoral fin to caudal peduncle orange; caudal peduncle and caudal fin (except for upper and lower edges which are pale-blue violet) jet black; a black band passing from snout through eye, broadening on to anterior portion of body and merging gradually with dusky orange on median part of body; a similar black band from snout to anterior third of back where it also merges with the orange; a narrow blackish line from slightly ventral and posterior to rictus to lower base of pectoral fin; narrow band on head between midlateral and middorsal bands chartreuse; head below midlateral band chartreuse, shading to pale blue ventrally; lips edged in bright red; abdomen pale blue shading to dull pale yellow posteriorly; dorsal fin orange basally, hyaline distally (only tips of interspinous membranes are hyaline whereas the outer half of the soft portion of the fin is clear); anal fin divisible by color into three lengthwise bands, light blue basally, orange in the middle, and hyaline distally; paired fins pale except for dark edges of pectoral rays.

The brightness of the life color of the holotype had already faded when the photograph of Plate 1 was taken. The orange of the body and especially the yellow green of the head were more brilliant when the fish was alive.

The specimen from Caroline Atoll, although exhibiting the same general color in alcohol, is more melanistic than the ones from Moorea. The median portion of the body is dusky, almost blackish, and the white margins of the caudal fin are narrower and restricted to the outer half of the fin.

The life colors were approximately the same. The color on the head was noted in life as dusky iridescent green; the middle of the body was dusky orange and the abdomen dusky yellow; the narrow band on the cheek was blackish orange; the edges of the caudal fin were hyaline violet; the lower lip was bright red and the upper mottled with red; the dorsal and anal fins were orange basally and hyaline distally, and the paired fins pale with a purplish hue.

One pair of *L. rubrolabiatus* at Caroline Atoll was seen in company with a juvenile which was iridescent blue with a broad midlateral black band. One of another pair showed intermediate coloration—the anterior half was bright blue with the black median band, and an orange-brown area was just appearing in the middle of the body.

L. rubrolabiatus is the smallest of the four species of *Labroides*. Individuals seen underwater rarely appear even slightly larger than the largest specimens collected. An excep-

tionally large one, estimated at between 60 and 70 mm. in standard length, was sighted on the top of a patch reef in the lagoon at Takaroa.

This species was first seen by me during a short stay at Caroline Atoll. It was abundant in the clear water off the lee reef, but was not seen in the lagoon (which lacks a pass). It was often seen in pairs, and commonly two of the little labrids picked rapidly over the body of a larger fish simultaneously, paying special heed to the head. Only a slight tendency toward the oscillatory swimming as described for *L. dimidiatus* was noted. It was seen to peck at the bodies of numerous parrot fishes (*Scarus* spp.) and surgeon fishes (*Ctenochaetus striatus* and *Acanthurus* spp.), the groupers *Cephalopholis argus* Bloch and Schneider, and *Plectropomus leopardus* (Lacépède) (3½ feet in length), the giant wrasse *Cheilinus undulatus* Rüppell (about 4 feet in length), the goatfish *Parupeneus chryserydros* (Lacépède), and the lutjanoid *Monotaxis grandoculis* (Forskål). Later at Tahiti and Moorea the list of species seen in association with *Labroides rubrolabiatus* was extended such that it encompassed nearly all the families of reef fishes in the area.

L. rubrolabiatus has been observed entering the gill cavities of parrot fishes. This was first seen at the entrance to the pass of the atoll of Takaroa in the Tuamotus. The labrid inserted the anterior half of its body through the gill opening of *Scarus harid* Forskål. The second observation was made just outside the barrier reef on the southeast coast of Moorea at a depth of 10 feet. About a 40 mm. *Labroides* was seen to pick several times at the right gill opening of *Scarus vermiculatus* approximately 250 mm. in standard length. The parrot fish angled its left side downward and elevated its gill covers. The labrid slipped into the gill chamber and was completely lost from view for about two seconds. On two occasions outside the reef at Takaroa *L. rubrolabiatus* was seen to enter the buccal cavity of adult groupers of the species *Epinephelus fuscogutta-*

tus (Rüppell) via the mouth.

The stomach of the paratype from Caroline Atoll was opened and found to contain one larval gnathiid isopod. The 45 mm. paratype from Moorea was similarly examined; this fish had eaten nine larval gnathiid isopods.

In the Society Islands and Tuamotus the species is not as common as *L. dimidiatus* or *L. bicolor*. It occurs outside the reef and in lagoons, usually at depths greater than 15 feet, and in areas of good circulation with much live coral and clear water.

At the atoll of Tikahau, Tuamotu Archipelago, outside the reef just north of the pass, *L. rubrolabiatus* was seen at a depth of 120 feet, in the company of a single *L. dimidiatus*. No specimens were collected from Tikahau or from Nuku Hiva in the Marquesas, where the species was also observed underwater.

Whether the species will be found to be restricted to southeast Oceania or whether it will eventually be taken farther to the west remains for further collections to reveal.

The species is named *rubrolabiatus* (Latin *rubro*, combining form of *ruber*, red; *labiatus*, lipped) in reference to the color of the lips in life.

lulu, and Dr. F. A. Chace, Jr., United States National Museum, Washington, D.C., for pertinent information.

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Metamorphosis of the Shell in the
California Sea Hare, *Aplysia californica* Cooper

Lindsay R. Winkler[1]

Despite attempts by Carazzi (1905), Mazzarelli (1893), Saunders and Poole (1910), and the present writer, the metamorphosis of *Aplysia* has not yet been observed, nor has it been possible to follow through the changes in the shell which take place as the animal metamorphoses from a planktonic veliger to a sluglike sea hare. This is because the veliger shell is lost sometime during metamorphosis so that the evidence of metamorphosis in the animal becomes obscured. In one case only has the writer seen a small outmoded veliger shell hanging in place by a very thin membrane in the apexial concavity of a very young specimen from a new species obtained from the Gulf of California.

However, the neaplysiids which are known only from the west coast of North America are distinct in that they possess a special attachment plate extending from the inner apexial area. This plate contains the built-in veliger and the metamorphic shell. This is best seen in young shells, as older animals tend to strengthen their shells by overlaying with added shell material.

MATERIALS AND METHODS

The shells of *Aplysia californica* Cooper, two to five inches in length, were procured from newly sacrificed young animals. The shells were preserved in 70 per cent alcohol. Study was done under a dissecting microscope.

EXPERIMENTAL DATA

The position of the metamorphic shell is indicated in Figure 1. The portion of this shell outline which normally comprises the veliger shell at hatching may be approxi-

mated by comparing the shell of laboratory incubated egg strings at the time of hatching with the inner areas of the shell nucleus. Size measurements are helpful in determining the areas involved in the prehatching shell. The size of the veliger from top of the hood is approximately 150 μ.

The angle of the hood in relation to the base of the shell at the time of hatching (Fig. 2), compared to the corresponding dimension in the shell nucleus, indicates the approximate starting point of free-living existence. The end of the pelagic period probably occurred at the time of the first major change in shell character in the area built after the initiation of free-living existence.

In many specimens the shell built between the time of hatching and this supposed end of the pelagic period is of slightly different color. It is a less transparent yellow and has fine growth lines, perhaps reflecting the change from the prehatching yolk food to the food that may have been available to it in the free-swimming state.

An examination of the veliger shell (Fig. 2) shows that the tendency to build a spiral shell is already indicated at time of hatching by the asymmetrically thickened edge of the initial spire. The tendency to spiral rapidly increases during the early postveliger existence. The writer believes that this is a crawling stage in which the snail's foot has taken over the locomotion for which it was not yet prepared at the time of hatching. This early stage, though very different from the adult, is probably very gastropodlike, with the animal crawling on its foot and feeding upon microscopic algal forms but retracting within its spiral shell which it closes with its operculum. This constitutes the first stage of metamorphosis.

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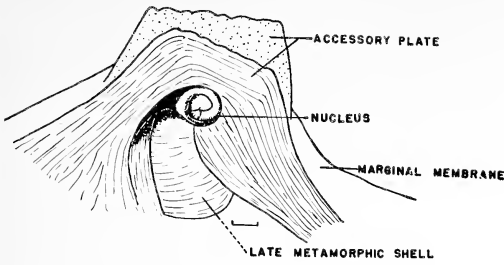
FIG. 1. Nuclear area of a shell of *Aplysia californica* Cooper showing the stages of development from the microscopic free swimming veliger to the adult plan of shell construction. The measure indicates 150 μ.

FIG. 2. Two views of newly hatched veliger larva. The measure indicates 150 μ.

As the shell completes its first convolution, it starts an even more marked tendency to flare out and flatten to form a covering over the animal rather than a house into which it may retract. At the end of the first whorl this tendency has become dominant, and by the end of the further half whorl the shell has opened out into a spoon-shaped covering which is indicated as the late metamorphic shell in Figure 1. Mazzarelli (1893) pictured a metamorphic animal which is probably a somewhat later form than this, carrying its outgrown shell on its back. During the metamorphosis, additional material is laid down on the shell, in which process the nucleus is probably first a point of muscle attachment. However, in *A. californica* an auxiliary plate is soon formed, paralleling the curvature of the intermediate metamorphic shell, which, along with later modifications, forms a new post-metamorphic plan of growth. This neaplysiid plate forms on a plane with the embryonic nucleus and becomes an extension of it.

The entire outline of the shell is modified after metamorphosis, the original larval shell being used only as a building block in the future adult shell. These shell changes are indicated in Figure 1 by the lines of growth.

SUMMARY

1. The shell nucleus, containing the veliger shell, is present in adults of *Aplysia californica* Cooper as a building block in the auxiliary plate characteristic of this subgenus.

2. The metamorphic forms of the shell are clearly preserved.

3. The implications of this shell metamorphosis are (a) a short swimming stage, (b) an intermediate, gastropodlike crawling stage in which the shell is a place of retreat, (c) a metamorphic stage with a spoon-shaped shell by which the animal is covered, and (d) a late metamorphic stage in which the animal outgrows the shell, which becomes vestigeal in the adult animal.

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Specific Characters and Character Variants in Adults and Larvae of the Genus *Paratrombium* Bruyant 1910 (Acari, Trombidiidae), with Descriptions of Two New Species from Western North America

Irwin M. Newell[1]

The genus *Paratrombium* was established by Bruyant for a larval mite, which he named *P. egregium*, found in a vial containing Diptera, Coleoptera, and possibly other insects. The outstanding characteristics of this larva as indicated in the drawings provided by Bruyant were: (1) the large postscutal dorsal plate, (2) the characteristically striate anterior portion of the scutum, (3) the form and orientation of the heavy, sharp prosensillar setae which appear to arise from the end of long canals, (4) the swollen, bilobed tip of the rostrum, (5) the elongate, pectinate tritorostral setae, (6) the heavy rakelike inner setae of coxae I, (7) the presence of a single pair of intercoxal setae, (8) the number (four) and orientation of the setae between coxae III and the anus, (9) the presence of only two scythe-shaped claws on tarsus III. In all of these features, the species described by Bruyant resembled so closely the one described below as *Paratrombium bidactylus* n. sp. as to indicate that these are congeneric.

It should be pointed out that the original description of *P. egregium* differs from *P. bidactylus* n. sp. in three important respects: (1) the presence of a pair of slender, elongate setae between the sensilla and prosensillar setae of the scutum, (2) a coxal setal formula in the larva of 2-1-1 compared with 2-2-1 in *P. bidactylus*, and (3) the possible absence of the four characteristic elongate setae at the posterior margin of the body. The first of these apparent differences is based on an artifact; for the transverse suture which partially divides the scutum into anterior and posterior portions appears so sharp and deli-

cate that Bruyant unquestionably mistook it for a fine seta. With regard to the second of these characters it should be pointed out that Oudemans (1910) represented this species as having two setae on each of coxae II of the larva; and moreover showed only four pairs of setae on the scutum, including the single pair of sensilla. Oudemans' somewhat more detailed figures were apparently prepared from Bruyant's own material, hence, the original description of *P. egregium* was in error on this point also. With regard to the third point mentioned above, neither Bruyant nor Oudemans showed the characteristic setae at the posterior end of the hysterosoma which are found in the larvae of *P. bidactylus*. It should be pointed out, however, that the writer's drawings have been made from unengorged larvae while those drawn by Bruyant and Oudemans were of engorged larvae. Both Bruyant and Oudemans showed a total of 28 postscutal and postcoxal setae whereas in *P. bidactylus* there are 30. This could be a true specific difference or it might possibly be due to the loss of one of the pairs of setae during the period of feeding in the specimens from which the available figures of *P. egregium* were drawn. At any rate, the close morphological similarity between *P. egregium* and the two species described below as *P. bidactylus* n. sp. and *P. quadriseta* n. sp. is so close as to indicate beyond reasonable doubt that they are congeneric.

The differences between the two larvae described below appear to be adequate to indicate that two distinct species are involved, and since they were obtained from known adult females, it is possible to determine what adult characters, if any, show variations of a

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possible specific nature. Correlations between larvae and adults in this group are much needed, because the two instars are often collected under quite different circumstances, with the adults coming from general collections, and the larvae often being found on their insect hosts. Because of the great change in form which accompanies the transformation from larva to nymph and nymph to adult in the Parasitengona, it is impossible to correlate larvae and adults with certainty by any means other than rearing.

There are even more compelling reasons, however, for establishing correlations between larvae and adults. In the first place, adults within a given genus of the Parasitengona are separated from each other by characteristics largely of a relative nature. The intraspecific variation in the adults of these mites is so great that it has not yet been adequately analyzed for any single species within the entire group. At the same time, *interspecific* differences are relatively small, so that in examining two adult specimens within a given genus, which show moderate differences, there is always the question of whether these differences are of a specific nature, or whether they fall within the range of variation of a single species. The primary difficulty here is that the chaetotactic differences which are of such great value in separating orthotrichous forms are almost totally unavailable in the highly neotrichous Parasitengona. With intensive study of the chaetotaxy of adults, exceptions to this are slowly coming to light, but they are at the present time very few in number, and it appears increasingly likely that there are certain genera in which absolute chaetotactic differences will never be of great importance in differentiating species. While it is to be hoped that it will never be necessary to have *both* larvae and adults in order to provide positive determinations of species, there is no assurance at this time, in the present inadequate state of our descriptive accounts of the adults of these species, that such will not be the case. Old species must be carefully

redescribed, and new species must be described in considerably greater detail and with far greater accuracy than they have been in the past if we are to progress in knowledge of the adults as far as we have in knowledge of the larvae.

In the second place, correlations between larvae and adults are necessary in order to provide additional information upon which to determine relationships within the Parasitengona. In very many cases, the best generic characters are found within the larvae, and in any case it is always well to have the larval characters in addition to the adult characters in arriving at conclusions concerning relationship. Here again, it should be pointed out that even recent descriptions of larvae of Parasitengona are inadequate from a morphological and systematic standpoint. All too often, for example, the chaetotaxy of the palpi is presented in a very sketchy manner, if at all, and the segments of the legs, despite their greater size, come out only slightly better. At the species level, detailed studies of the larvae of closely related species are desirable in order to substantiate the validity of minor differences suspected of having specific value in the adults. For example, in the present case, there are a few very minor differences between the adults of *Paratrombium bidactylus* and *P. quadriseta*. If one had only the adults of these two species, there would be considerable doubt whether the differences in eupathidial counts on the palpal tarsus, the slight difference in the posterior end of the crista metopica, the chaetotaxy of the anterior portion of the scutum, and the number of setae on genital and paragenital sclerites were of real specific value. It is still possible that studies of additional adults will show these characters to intergrade at least in part. Yet the studies of the larvae show clearly enough that we have two distinct species, hence any differences found between adults of these two species are of possible specific value, and are worth investigating in detail.

In the present paper, the terminology uti-
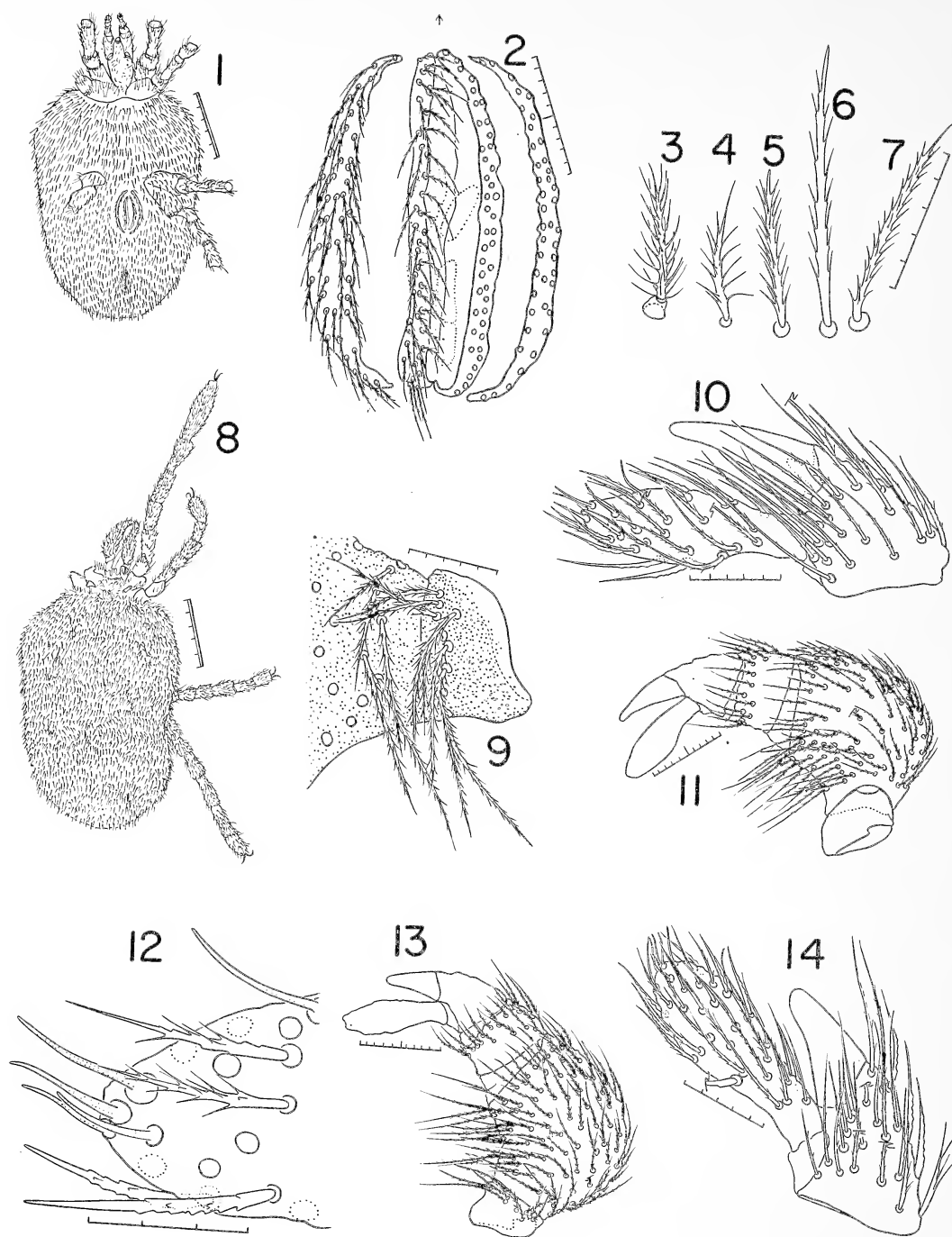
Figs. 1–14. *Paratrombium bidactylus* n. sp., female: 1, venter, female; 2, genital opening; 3, typical seta posterior and lateral to anus; 4, seta from genital sclerites; 5, seta from intercoxal area; 6, seta of coxa II; 7, seta behind the coxa II; 8, dorsum; 9, trochanter of palp, posterior; 10, tibia and tarsus of palp, anterior; 11, entire palp, anterior, chaetotaxy of tibia and tarsus omitted; 12, tip of palp, posterior; 13, entire palp, posterior; 14, tibia and tarsus of palp, posterior.

lized in the earlier work on the Johnstonian-idae (Newell, 1957) has been followed, as has the convention for designation of the positions of setae on the segments of the appendages. The decimal system of notation has been extended to the scutum as well as the appendages. In the case of the scutum, the starting point (0.00) will be the most anterior point on the median line of the scutum. In *Paratrombium* and many other genera, the anterolateral lobes of the scutum actually extend beyond this point, but since these are rather poorly defined in some genera or in particular specimens of many species, it is better to utilize the more readily recognizable point. In general this will be the most anterior point on the median axis of the scutum, regardless of whether or not this is precisely the anterior end of the entire plate.

Attention should be called to the indiscriminate use of the term crista metopica. This term was applied by early authors to the very pronounced ridge which runs longitudinally over the dorsum of the propodosoma of many species of the Parasitengona. It is primarily a strengthening support for the dorsal wall of the propodosoma, and also provides attachment for certain of the muscles of this part of the body. It should be kept in mind that the crista metopica is only one part of a larger sclerite, the scutum, which is of considerably greater significance both structurally and taxonomically than the crista metopica alone. The crista metopica, because it is so much more conspicuous than the scutum (the margins of which are often so faint as to be detectable only in carefully dissected and mounted material), is often described as though it were an isolated structure in itself. In a few of the Parasitengona it does approach this status, especially in some of the larger Erythraeidae in which the scutum is only very slightly broader than the crista. At some points the crista in certain genera may even be the *only* portion of the scutum to be found. However, such cases are extremely rare; and there are few species in which the

scutum does not extend at least somewhat beyond the limits of the crista metopica. The neglect of the peripheral portions of the scutum in descriptive accounts is a serious omission. It is also a mistake to extend the term crista metopica to apply to the scutum as a whole. A description of the scutum should be based upon dissected material, or if this is impossible, upon carefully compressed specimens in which all levels of the scutum are lying in approximately the same plane.

PARATROMBIUM Bruyant 1910

ADULT: Trombidiidae of medium to large size, and brilliant red color. Scutum with sensilla in middle one-third of plate, widest portion of scutum at anterior end; crista extending from posterior end of scutum to a group of setae near the most anterior point on the midline of the scutum. Eyes distinctly stalked, two corneae on each side. Dorsal hysterosomal setae all of one type, peripectinate, arising from small, erect, conical papillae. Coxal rings I and II open dorsally, a long slender supracoxal seta on I. Genital and paragenital sclerites both well developed and bearing numerous peripectinate setae; three pairs of genital acetabula. Tarsus of chelicera bearing a row of minute denticles along the upper margin, this row of denticles also continuing down over the side of the basal portion of the tarsus (Figs. 22,

55). Palpi of normal form for family, odontus unidentate, paradont absent. Tibia with no clearly defined ctenidium, but with a group of unusually smooth setae anteroventrally, near the insertion of the tarsus. Tarsus with a single solenidion posteriorly and a variable number of eupathidia.

LARVA: Scutum with four pairs of setae, postscutum with two or four pairs; postscutum nearly as wide as scutum. Coxa I with a slender supracoxal seta and two ventral setae, the medial one of which is greatly enlarged and bears a number of long, finger-like teeth on the posterior margin. Urstigma very large, concealed under the posterior margin of coxa I in ventral view, visible only by transparency. A single pair of intercoxal setae. *Lassenia*-organ present. Palpi with only four segments visible in ventral view, but trochanter present as a very small plate dorsally on base of palp (Fig. 40). Palpi oriented so that the morphological dorsal line forms the lateral margin of the palp as seen in dorsal or ventral view. Trochanter and patella devoid of setae, femur with a single seta. Tibia with a deeply cleft odontus plus three simple setae; no specialized paradont present. Tarsus reduced to a small hemispherical cap bearing a number of setae of variable size and form, but one of these is strongly scythe-shaped. Rostrum with only the protorostral and tritorostral setae. Basifemur and telofemur of all legs fused. Solenidial formula of patella (2-1-1), of tibia (2-2-0), and of tarsus (1-1-0). Vestigial setae present on patella I and II and tibia I, famulus on tarsi I and II; companion setae absent. Tarsi I and II with three claws each, III with anterior and median claws of same form as on I and II, but with posterior claw reduced to a very short rudiment (at least in the type species and the species described in this paper).

<center>CHARACTERS SHOWING INTERSPECIFIC VARIATIONS IN THE GENUS *Paratrombium*</center>

Although the study of interspecific variation within a genus is of practical value in the identification of species, this should never be regarded as the sole purpose of such studies. Any type of variation observed, whether of practical utility in a key or not, should be investigated as it may indicate relationships within the genus, or evolutionary trends. When combined with similar studies in related genera, they provide information on whether or not the same types of adaptive changes have occurred in different genera. In the large Parasitengona, intensive studies of variation are even more important than in the other genera, because the differences separating species are more often of a purely relative nature; that is, they involve variations of continuous rather than discontinuous types. As a consequence of the studies of the two forms described here, a number of characters were discovered which show variations of possible specific value. These are summarized below, the characters for adult and larva being listed separately. Most of the character variants listed in the tables are self explanatory, but some require further explanation. Most of them show variation of a continuous type. One exception is found in the dorsal chaetotaxy of the larva, in which the postscutum has two setae in one of the species and four in the other. These variants are discontinuous only in the sense that no intergradations between them have been found up to the present time. While it is not inconceivable that these exist, it is interesting to note that the closest approach is found in occasional specimens of *P. bidactylus* in which there are two setae on one-half of the postscutum. Even in these cases, the half of the postscutum in which the duplication has occurred does not resemble its counterpart in *P. quadriseta*, since the placement of the two setae is markedly different.

The variations in form of the hysterosomal setae (character 14, adult) are more or less discontinuous, although it is quite certain that many gradations will be found when the genus is more adequately known. If Feider's assumption (1952) that nearly all species of
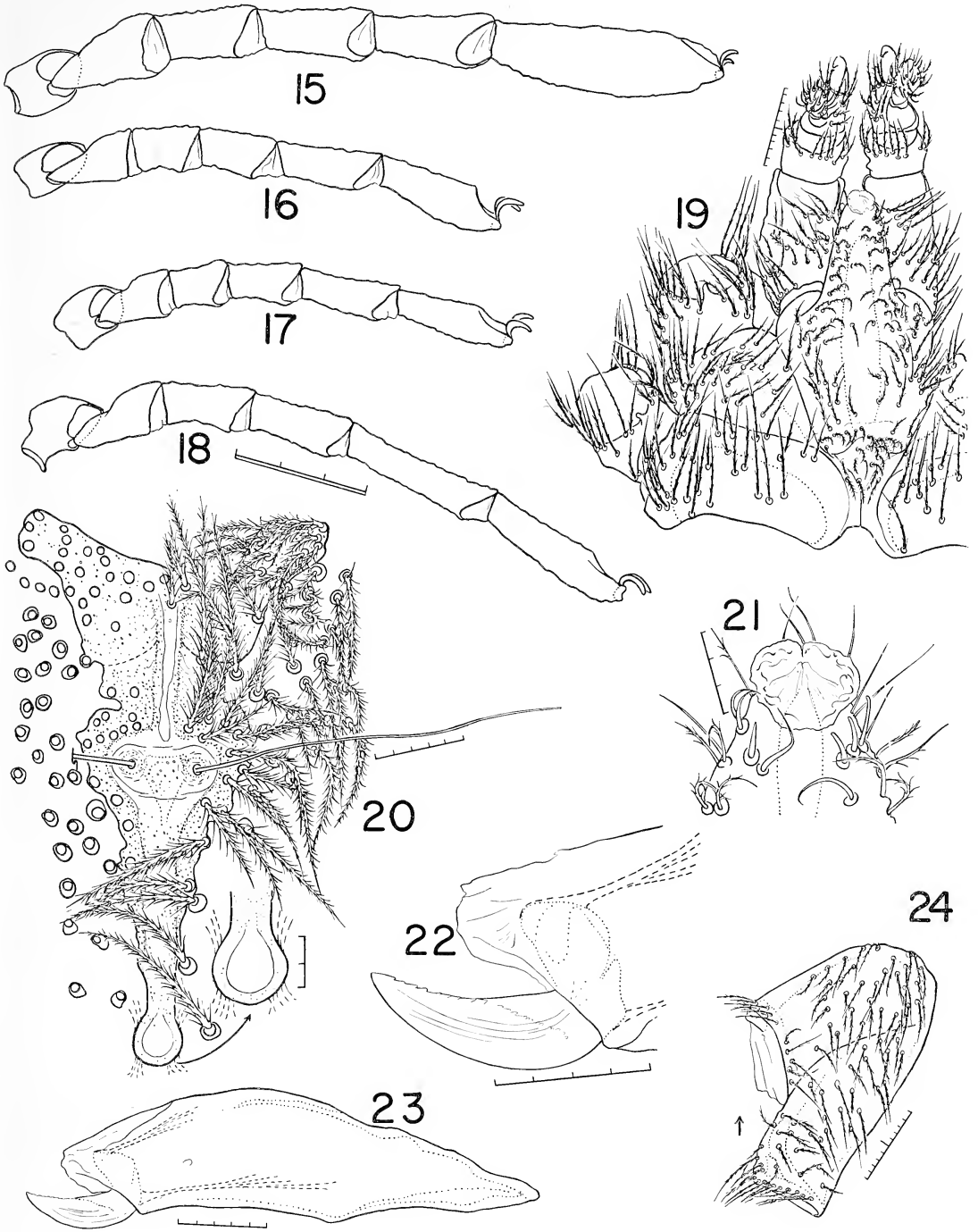
FIGS. 15–24. *Paratrombium bidactylus*, n. sp., female: 15–18, legs I to IV; 19, gnathosoma and propodosoma, ventral; 20, scutum of dissected female; 21, tip of rostrum, ventral; 22, cheliceral detail; 23, chelicera; 24, coxae III and IV.

the old genus *Dinothrombium* actually belong in *Paratrombium* is correct, the probability of intergradation in setal types is very great.

Nearly all of the characters listed below show variants which are useful in distinguishing the two species under consideration here. It is to be expected that as more species are adequately described even more characters and variants can be added to this list. At the same time, as other populations of the two species involved are studied, the range in variation of the characters will become greater. The variants of the characters are summarized in the form of a formula key. The purpose of such a key is not so much the identification of species, as to provide a convenient means of summarizing the observed ranges in the character variants. Of course, species identification can be made simply by selecting certain of the more easily interpreted characters and determining the particular variant of each character which is found in the specimen or specimens at hand. In the case of the adult, the most easily interpreted characters are 1, 3, 6, 12, and 14. Few larvae have been described at the present time so that it is impossible to say what will be the most reliable characteristics. In the case of the two species described here, the form and chaetotaxy of the postscutum, and the position of s_1 (characters 1, 4, 10, 11, and 12) are the most easily applied. So far as the present data are concerned it must be remembered that the measurements shown in the tables of distribution of character variants in the case of the larva, are based upon the progeny of a single female, and the variation of the species as a whole must be greater than that shown in the table. In the case of the adult only one specimen in each case was involved; where a range is indicated, this is based on the variation on right and left sides of the one specimen. This is admittedly undesirable from the standpoint of an analysis of variation in the species, but at least it is a beginning and shows the probable direction which future attempts at the measurement and expression of interspecific and intraspecific variation should take in *Paratrombium* and related genera.

Characters such as the number of setae on each anterolateral lobe of the scutum of the adult are likely to be quite variable and to show intergradation between similar species. Nevertheless, it is obvious that the number of setae on the scutum will still be of value in separating species which are markedly dissimilar with respect to this character. The same is true of such characters as the number of setae on the genital and paragenital sclerites, the number of eupathidia on the palpal tarsus, and the proportions of tarsus I and tibia I. Characters dealing with the positions of setae on the leg segments have seldom been used in the differentiation of species, nor should they be used critically unless some work has been done to assess their variability in a series of specimens. A study of characters 4, 5, 6, 7, and 8, dealing respectively with the positions of s_1, e_d of tarsus I, f_1, s_2, and f_2, shows that in all of these cases the distribution of these setae overlaps in the two species. However, the mean positions show some variations which are certainly significant for the material studied, and probably for the species as a whole. Thus, while f_1 and e_d are at essentially the same level in the two lots of larvae studied, s_1 is considerably more distally placed in *P. bidactylus*, and the range in position of this seta in the two species barely overlaps. The same tendency toward distal placement of s_2 and f_2 in *P. bidactylus* is also seen, although the ranges overlap more than in the case of s_1.

In the tables of distribution of character variants, those variants given by Feider (1952) for *Paratrombium divisipilli* Feider 1948 (*P. d.*) are included wherever possible [here I use the name *P. divisipilli* as a specific rather than a varietal name, since it appears possible that *P. insulare* (Berlese) 1910 and Feider's form may eventually prove to be distinct species]. Where superscripts are given, these indicate the number of measurements on which a given range and mean are based.

SUMMARY OF CHARACTERS AND VARIANTS
IN ADULTS OF *Paratrombium*

1a. Sensilla smooth (Fig. 77).
1b. Sensilla distinctly barbed (Fig. 76).
2. Number of setae on each anterolateral lobe of scutum (from constriction anterior to area sensilligera to anterior extremity, and omitting the medial setae).
3a. Posterior end of crista metopica distinctly swollen (Fig. 20).
3b. Posterior end of crista metopica not swollen (Fig. 50).
4. Number of setae on each genital sclerite.
5. Number of setae on each paragenital sclerite.
6a. Row of denticles on tarsus of chelicera distinctly bent near the middle (Fig. 22).
6b. Row of denticles on tarsus of chelicera forming a straight line (Fig. 55).
7. Position of solenidion of palpal tarsus.
8. Number of eupathidia on palpal tarsus.
9. Length of tarsus I, female.
10. Height of tarsus I, female.
11. Length of tibia I, female.
12. Length/height, tarsus I, female.
13. Tarsus I/tibia I, female.
14a. Hysterosomal setae tapering uniformly, peripectinate (Figs. 3–7).
14b. Hysterosomal setae rounded distally, clavate, peripectinate (as in *Paratrombium insulare* Berlese 1910).
14c. Hysterosomal setae diclavate, i.e., essentially clavate, but deeply bifid (as in *P. divisipilli* Feider 1948).
15. Body length, by sex.

SUMMARY OF CHARACTERS AND VARIANTS
IN LARVAE OF *Paratrombium*

1a. Postscutum with two setae in normal individuals.
1b. Postscutum with four setae in normal individuals.
2. Total number of postscutal and postcoxal setae.
3a. Palpal tarsus with only two minute, peg-like setae terminally (oil immersion, Fig. 35).
3b. Palpal tarsus with four setae here (not distinct except in most favorable material).
4. Position of s_1.
5. Position of e_d on tarsus I.
6   Position of f_1.
7. Position of s_2.
8. Position of f_2.
9a. Posterior claw reduced to a minute vestige about 4 μ long.
9b. (Other variants?)
10. Length of scutum/length of postscutum.
11. Width of scutum/width of postscutum.
12. Width of postscutum/length of postscutum.
13. Width of scutum, μ.
14. Length of idiosoma of unengorged larva.

Paratrombium bidactylus, new species

FEMALE: Idiosoma 1820 μ long to tip of scutum, 1118 μ wide, length/width 1.63. Scutum (Fig. 20) widest at anterior end, the width equal to .62 of the *median* length. The

DISTRIBUTION OF CHARACTER VARIANTS, ADULTS

	1	2	3	4	5	6	7	8	9
P. b.	a	22–25	a	37–39	26–29	a	.87–.92	11	486–491 μ
P. q.	b	13–14	b	48–55	ca. 55	b	.80–.85	17–19	423 μ
P. d.	b	?	a	?	?	?	?	?	454–474 μ (462)

	10	11	12	13	14	15
P. b.	153 μ	261 μ	3.24	1.86–1.90	a	1820 μ*
P. q.	144–149 μ	261–266 μ	2.84–2.94	1.59–1.62	a	1768 μ*
P. d.	?	232–261 μ (252)	?	(1.83)	b	♀ 1638–1885 μ (1816) ♂ 1085–1740 μ (1402)

* Based on females which had laid full complement of eggs.

DISTRIBUTION OF CHARACTER VARIANTS, LARVAE

	1	2	3	4(s₁)	5(e_d)	6(f₁)	7(s₂)
P. b.	a	30	a	$.47–.52(.49)^9$	$.65–.71(.69)^9$	$.45–.58(.53)^9$	$.47–.54(.51)^{10}$
P. q.	b	32	b	$.35–.48(.42)^{10}$	$.64–.71(.66)^{10}$	$.38–.55(.51)^{10}$	$.40–.50(.45)^{10}$
P. d.	a	?	?	?	?	?	?

	8(f₂)	9	10	11	12	13	14
P. b.	$.45–.55(.51)^{10}$	a	2.43^{11}	1.09^{11}	2.92^{11}	$216–236^{11}$	$387–441\ \mu^{10}$
P. q.	$.35–.49(.43)^{10}$	a	3.38^9	1.23^9	3.51^9	$188–208^9$	$356–383\ \mu^5$
P. d.	?	a	2.76^1	?	2.15	(compressed)	$331–351\ \mu$

anterolateral lobes of the scutum, extending from the anterior end to .21 are well developed, bearing 22 to 25 setae on each side, most of which are concentrated on the lateral arms. Sensilla situated at .39, appearing completely smooth even at magnifications of 1000× (oil immersion). Beginning at .32 and extending anteriorly is a deep furrow which widens gradually as it approaches the anterior margin of the scutum; at about .05 this furrow widens abruptly and disappears on the general surface of the scutum. In the specimen studied, there are three setae at the level at which the furrow disappears. Behind the constriction at .21, the scutum widens perceptibly around the area sensilligera and then tapers gradually toward the posterior end. At .79, the scutum is reduced to the thickness of the crista metopica alone. The crista is distinctly swollen between .90 and 1.0, with pigmented cuticle completely encircling the depression in the end of the crista. In the portion of the scutum between .21 and .79, there are 31 elongate peripectinate setae similar in form to those on the anterior portion of the scutum. In the specimen examined, 16 of these are on the left side and 15 on the right side. The marked indentation at .27 in the specimen from which Figure 20 was drawn was absent from the other side of the scutum. The elongate peripectinate setae on the surface of the propodosoma lateral to the scutum are borne on subconical papillae as are those on the hysterosoma. Ocular plates pedunculate, bicorneate. Anterior margin of hysterosoma projecting well beyond the posterior margin of the propodosoma so that the pos-

terior portion of the scutum is hidden in dorsal view; setae along anterior margin of hysterosoma somewhat more slender and also smoother than those covering the rest of the body. Otherwise the setae of the hysterosoma are all of one type, heavily barbed, peripectinate, and the alveoli are at the apex of truncate conical papillae.

Setae of coxae I and II fairly stiff, peripectinate for about three-fourths their length, then smooth out to the usually rounded tips. Pars medialis coxae of rather unusual form, arising from inner angles of coxae I, and forming a narrow border about 15 µ wide around the convex inner angle of coxae II. The pars of right and left side are contiguous medially and may even appear to be fused in undissected specimens (Fig. 19). The pars medialis coxae contain 5 to 8 setae each, and because of their close approximation, the intercoxal area is completely isolated from the membranous cuticle behind the coxae; it contains between 25 and 40 closely packed peripectinate setae, somewhat shorter and thicker than the ones behind coxae II. Supracoxal seta slender, smooth; coxal ring of I and II both open dorsally. Membranous cuticle between coxae II and III apparently devoid of sclerites. Coxae III and IV as shown in Figure 24, coxal rings complete dorsally. No trace of a *Lassenia*-organ was seen at coxa III although the dense vestiture may have concealed it. Genital and paragenital sclerites both well developed (Fig. 2); genital sclerites with 48 to 55 peripectinate setae each, the paragenital sclerites with about 56 setae each. Most of the setae have four to six whorls of barbs
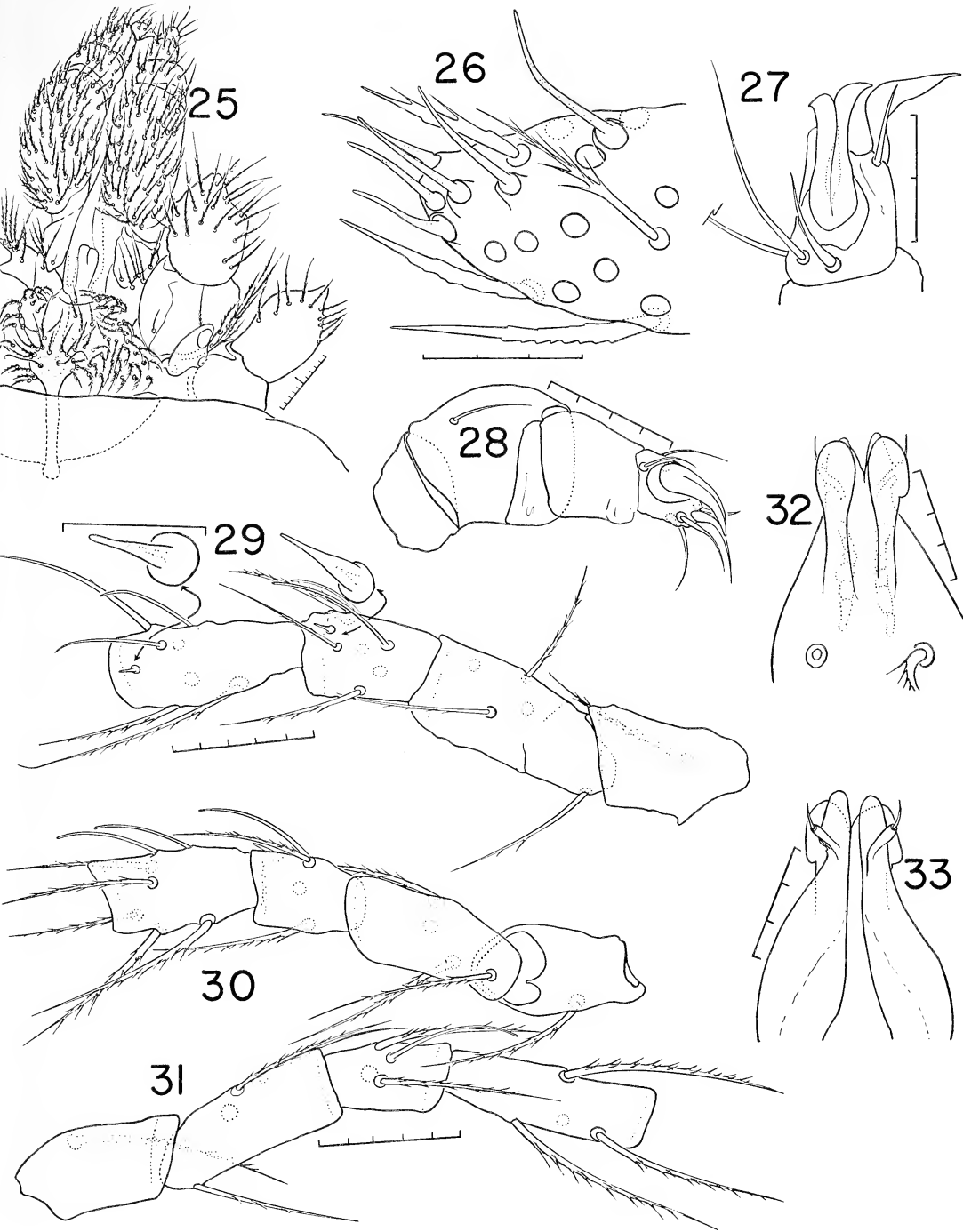
FIGS. 25–26. *Paratrombium bidactylus*, n. sp., female: 25, propodosoma, dorsal; 26, tarsus of palp, anterior.

FIGS. 27–33. *Paratrombium bidactylus*, n. sp., larva: 27, tibia and tarsus of palp, dorsal; 28, entire palp, anterior; 29, trochanter to tibia I; 30, trochanter to tibia II; 31, trochanter to tibia III; 32, tip of rostrum, ventral; 33, same, dorsal.

each, but one or two of the setae at the posterior end of the genital sclerites are very nearly smooth. Three pairs of genital acetabula placed well back in the genital opening, decreasing in size from anterior to posterior. Anal sclerites present, but so well concealed by surrounding setae that their form and chaetotaxy were not ascertainable. Ventral hysterosomal setae arising from truncate, conical sclerites (Fig. 3).

Base of gnathosoma with posterior ventral margin deeply concave; both base and rostrum with numerous curved, peripectinate setae. Velum simple, circular in outline, containing a central circlet of converging fimbriae. Four or five very slender, sparsely peripectinate setae arising from distidorsal surface of rostrum, and extending beyond the tip of the rostrum. Four or five setae arranged in a diagonal row posterolaterally to the velum. On the ventrolateral aspect of the rostrum are blunt setae, roughly rounded and smooth at the tips (Fig. 21).

Chelicerae (Figs. 22, 23) arched dorsally, fairly straight along the ventral margin. Dorsal membrane well developed and blunt. Tarsus of chelicerae with a row of 8 to 10 dorsal teeth in the distal half; at about the middle of the dorsal margin the row of teeth bends sharply down over the side of the tarsus where an additional 12 or 13 teeth of progressively diminishing size are found. Trochanter of palp with 9 or 10 elongate peripectinate setae in a fairly straight row down the posterior surface of the segment; anterior surface of trochanter bare, distal margin distinctly excavated. Odontus of tibia very heavy, undivided. Setae of tibia ranging from nearly smooth on anterior and posterior surfaces to very heavy and serrate along the dorsal margins. It is not known whether these setae are primarily serrate, or whether this condition arises as a result of a wearing or breaking off of the barbs. All of the setae of the tibia, with the exception of the odontus, are long, slender, and fairly flexible; no ctenidium is present. Each palpal tarsus in the specimen studied with 11 eupathidia ranging from .56 or .68d to .95 or .96v; the solenidia lie at .87 to .92p (one on each tarsus). The striated appearance of the solenidion is apparent only under favorable conditions.

Tarsus I 486–495 μ long, 153 μ high, length/height 3.24; tibia I 261 μ long, tarsus I/tibia I 1.86–1.90 (one specimen).

LARVA: Idiosoma (Figs. 41, 44) 387 to 441 μ long, 225 to 252 μ wide, length/width 1.73 to 1.88; average of 10 unengorged larvae 419 by 234 μ, length/width 1.80. Anterior margin of scutum truncate, with two heavy setae inserted dorsally just behind the margin; rostrum and palpi extending beyond the margin of the scutum. Just anterior to the level of coxa I is a prominent suture on either side of the scutum, these sutures not quite reaching to the lateral margin. Anterior to the sutures the margin of the scutum is characteristically marked by undulating striae. The remainder of the scutum is densely and uniformly punctate. Sensilla and the neighboring setae faintly barbed, the prosensillar setae completely smooth. Postscutum virtually as wide as the scutum (average ratio 1.09, 11 specimens), faintly punctate, bearing a pair of setae behind the middle of the plate. Ocular plates very small, bicorneate, completely lateral in position. Including the setae of the postscutum, there are 24 peripectinate dorsal and marginal setae; venter with 6 peripectinate postcoxal setae, making a total of 30 postcoxal and postscutal setae. Except for setae of postscutum, all these are borne on individual sclerites which bear a few punctae. Membranous cuticle appearing smooth at low magnifications, but faintly striate at higher magnifications.

Coxa I with a greatly enlarged rakelike seta anteromedially, bearing 10 to 15 digitiform teeth, identical in form with corresponding seta of *P. quadriseta* n. sp. (Fig. 63); anterolateral seta of coxa I elongate, slender, peripectinate. Coxa I with an elongate, sharp supracoxal seta; II and III without such a seta. Urstigma large. Coxae II and III sep-
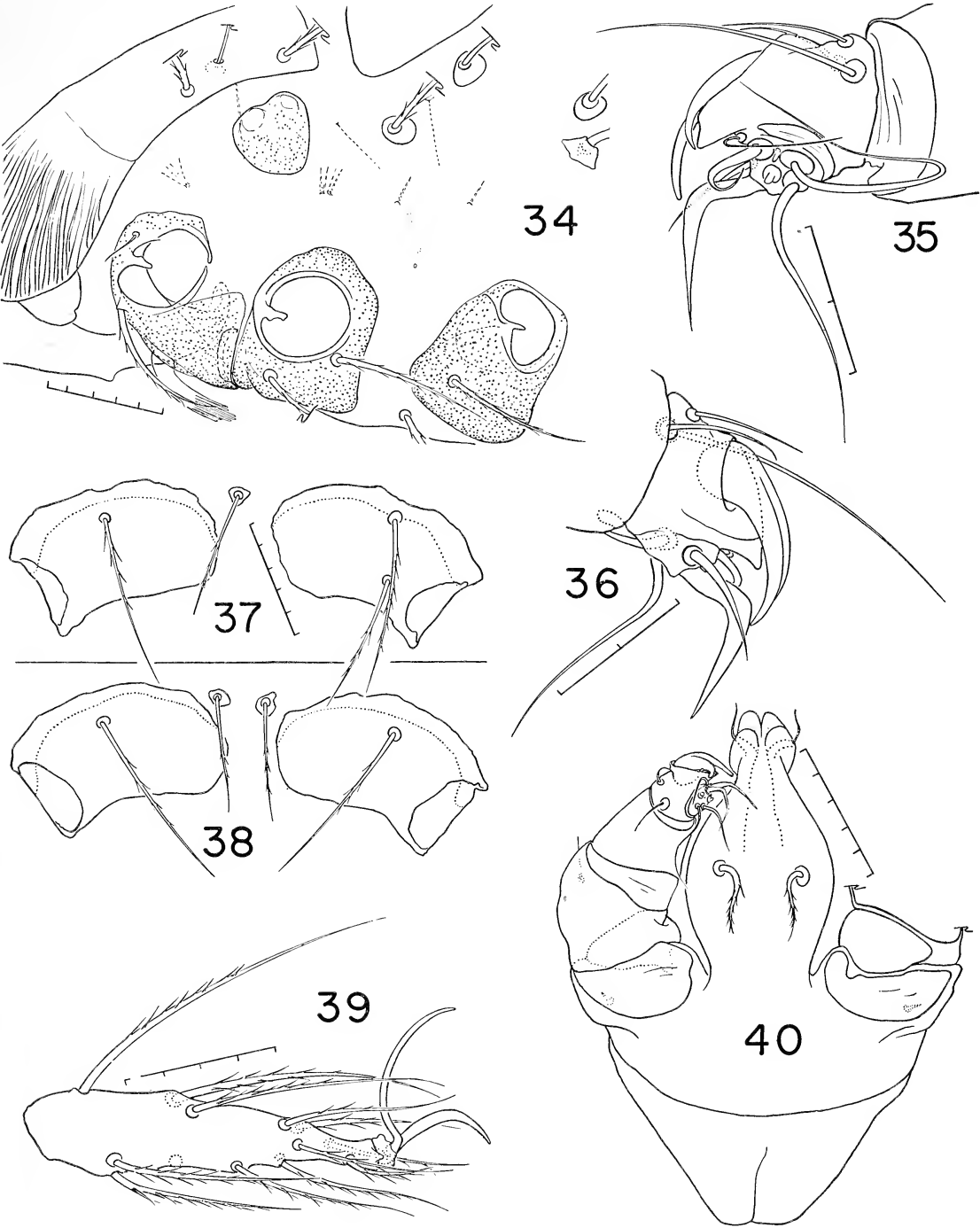
Figs. 34–40. *Paratrombium bidactylus*, n. sp., larva: 34, propodosoma, lateral, showing apodemes and *Lassenia*-organ; 35, tibia and tarsus of palp, posterior; 36, tibia and tarsus of palp, anterodorsal; 37, setal anomaly in coxa III; 38, normal chaetotaxy at level of coxa III; 39, tarsus III; 40, gnathosoma, ventral.

arated by a distinct interval of striated cuticle, bearing two and one setae respectively. Intercoxal area with a single pair of setae between III. In one specimen (Fig. 37) there was only one intercoxal seta, but coxa III of the left side bore a supernumerary seta in the posterolateral corner which evidently represented the displaced intercoxal seta. Postcoxal area with only three pairs of ventral and submarginal setae. Anal anlage very well developed. A small but distinct *Lassenia*-organ can be seen laterally between coxae II and III in good specimens; it is seen to best advantage in somewhat rotated individuals (Fig. 34). In the specimen drawn, the pore had a diameter of slightly more than 1 μ, and opened into a duct about 22 μ long, the inner end of which was slightly swollen. This is unquestionably the homologue of the same organ in *Lassenia* (Johnstonianidae) in which it is better developed. The function, if any, is unknown; it is not an apodeme.

Base of gnathosoma with posterolateral margins converging to a rounded or truncate end posteriorly; devoid of setae, except for the minute spikelike supracoxal setae which are dorsal in position (Fig. 40). Protorostral setae smooth, inserted at the ends of a pair of characteristic tubular structures on the dorsal lobes of the velum. Deutorostral setae totally absent, tritorostral setae peripectinate, situ-

ated at about the widest part of the rostrum. Palpi five-segmented, but trochanter reduced to an ovate plate on the dorsal surface of the palp (see Fig. 72, *P. quadriseta*). The inner angle of the trochanter can be seen projecting beyond the anterior margin of the palp where at first it may appear to be a lobe on the femur (in Figure 40, the ventral portion of the left femur has been deleted to show the position of the trochanter). Femur with a smooth seta on dorsal surface, quite variable in position. Patella without setae. Tibia with three smooth setae plus the deeply cleft odontus; no specialized paradont. Tarsus reduced to a small cap on the anterior aspect of the tibia bearing only 7 setae (Fig. 35). These include the large apical L-shaped seta (possibly a modified eupathid?) plus 5 other normal setae of varying lengths and thicknesses. In the center is a minute peglike solenidion scarcely discernible even under oil immersion, plus one other seta of similar form. The palpi of this species are remarkable for the geniculate form, which considerably alters the normal morphological relationship of the palpi with the rostrum. The morphological dorsal line forms the lateral margin of the palp as seen in ventral or dorsal view.

Chaetotaxy of legs approximately as shown in table (s = solenidia, e = eupathidia, f = famulus, v = vestigial setae, c = companion setae, n = normal setae).

	tr	fe		pa			ti			ta			c
	n	n	s	v	n	s	v	n	s	e	f	n	c
I	1	5, 6	2	1	4	2	1	5	1	2	1	17	0
II	1	4	1	1	3	2	0	5	1	0	1	14	0
III	1	4	1	0	3	0	0	5	0	0	0	13	0

Basifemur and telofemur of all legs fused. Patella I with solenidia at .28 and .45d, II and III with solenidia at .34 and .39d, respectively. Patella I and II each with a solenidion at .79 and .77d, respectively. Tibia I with solenidia at .56 and .75d, a vestigial seta at .90pd; II with solenidia at .39 and .56. The solenidia of the tibia show no readily perceptible difference in form. Tarsus I with S_1 at .47 to .52, a dorsal eupathid (e_d) at .65 to .71d, and a

famulus at .45d to .58d. Tarsus II with S_2 at .47 to .54pd and f_2 at .45–.55; III with no specialized setae. Other chaetotactic features as shown in table. Tarsi I and II with three claws each, the median claw more slender than the anterior and posterior claws; III with posterior claw reduced to a minute vestige about 4 μ in length as in the case of *P. quadriseta* n. sp. (Fig. 74).

TYPE LOCALITY: Sherwood Creek, Mason
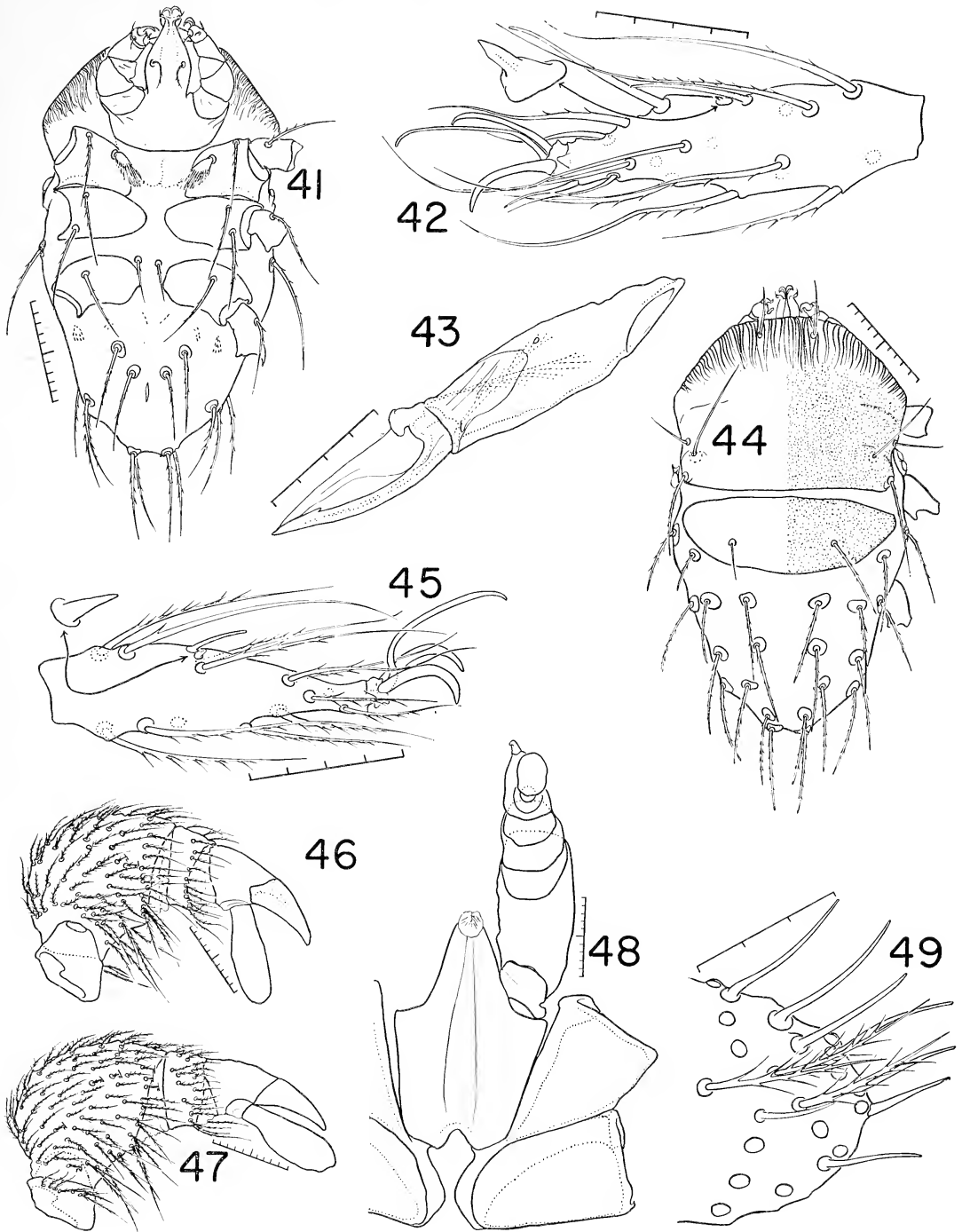
FIGS. 41–45. *Paratrombium bidactylus*, n. sp., larva: 41, venter; 42, tarsus I, posterior; 43, chelicera; 44, dorsum; 45, tarsus II, posterior.

FIGS. 46–49. *Paratrombium quadriseta*, n. sp., female: 46, palp, anterior; 47, palp, posterior; 48, outline of propodosoma and gnathosoma, ventral; 49, detail of end of palpal tarsus, posterior.
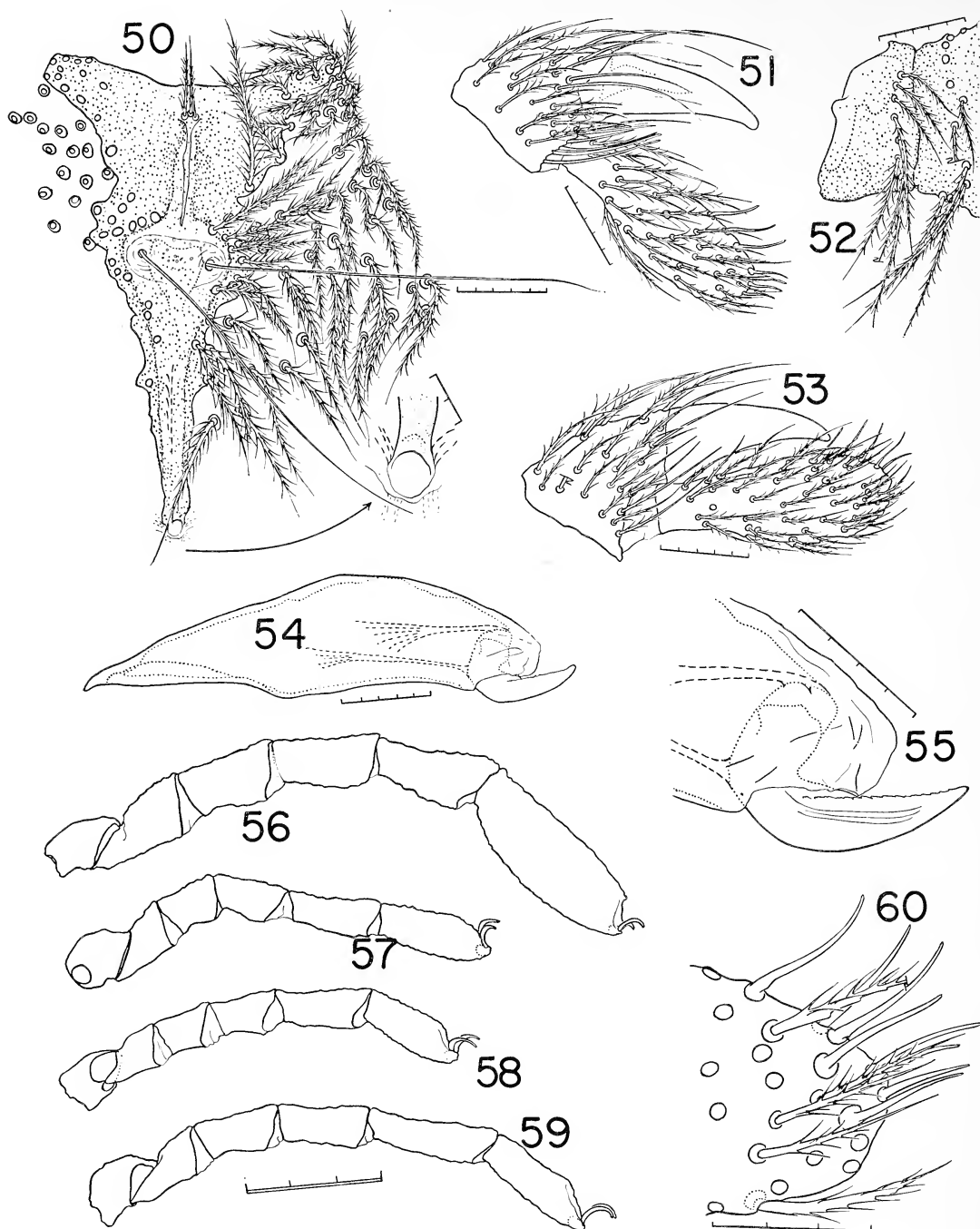
FIGS. 50–60. *Paratrombium quadriseta*, n. sp., female: 50, scutum of dissected specimen; 51, tibia and tarsus of palp, anterior; 52, trochanter of palp, posterior; 53, tibia and tarsus of palp, posterior; 54, chelicera; 55, tarsus of chelicera; 56–59, legs I–IV; 60, tip of palpal tarsus, anterior.

County, Washington. Sandy mud, in grass. July 27, 1954. Collected by the writer. At the point where this species was found, Sherwood Creek is estuarine, opening into Case Inlet of Puget Sound. The mites were collected on a low mound which was nearly covered by high tide.

REMARKS: The correlation between the larva and adult described above was established by rearing from eggs laid by the female collected at the type locality.

The relationship of this species to described forms is somewhat obscure, but there is no doubt that it is congeneric with *P. quadriseta* n. sp. The adult keys out with some slight inconsistencies to the genus *Caenothrombium* Oudemans, 1927, and agrees with the type of that genus in a number of details, including the general form of the crista, the double, stalked eyes and the absence of a distinct ctenidium on the tibia of the palp (there is definitely no distinct ctenidium in *P. b.* and *apparently* none in *C. caloris*). However, the larva does not appear to be congeneric with the larva of *C. miniatum* Womersley, 1934, for which species Womersley has established a correlation. Differences, as far as can be judged from Womersley's figures of this larva (1939*a:* 156), are in the chaetotaxy of the scutum, the absence of the heavy comblike seta of coxa I and the undivided (?) odontus. The drawings in the original description of the larva are not complete, but they probably are fairly accurate in these three respects. The larva of *P. bidactylus* keys out to the third dichotomy in the key given by Thor and Willmann (1947: 484). At this point further separation was made on the basis of the claws of tarsus III—whether these are normal, or whether the posterior claw (inner-claw) is deformed. Neither of these fits *P. bidactylus* or *P. quadriseta* accurately, and the key, as well as the diagnosis of the genus given by Thor and Willmann, were in error on this point. The fourth dichotomy of that key is totally unreliable since it is based upon the presence or absence of setigerous sclerites behind the

postscutum. It is quite likely that these have been overlooked by many authors in describing their species because of refractive index difficulties.

An examination of the drawings of the larva of *P. egregium* presented by Bruyant, Oudemans, and Thor and Willmann shows a close similarity between *P. bidactylus* and *P. egregium* Bruyant, 1910. The similarity is indicated in the shape of the scutum, the form of the prosensillar setae and their insertion at the ends of long canals, the heavy pectinate tritorostral setae, the comblike seta of coxa I and the chaetotaxy of the body, especially the ventral setae. These forms are extremely similar, and the resemblance is far too close to be a consequence of convergence; hence we can assume that they are actually very closely related.

The foregoing discussion leaves a number of important questions. For one thing, is the genus *Caenothrombium* made up of generically related species, or is it a composite? Was Womersley correct in assigning his *Caenothrombium miniatum* to that genus? Was the female which laid the eggs from which Womersley described the larva actually *C. miniatum* or a different species? There seems to be no way in which these questions can be resolved by reference to the literature, so further speculation about them is pointless.

Paratrombium quadriseta, new species

FEMALE: Idiosoma, 1,768 μ long to tip of scutum, 1,092 μ wide, length/width 1.62. Scutum of dissected female (Fig. 50) resembling that of *P. bidactylus* in most details. However, the anterolateral lobes of the scutum, extending from about .25 to the anterior limits of the scutum bear only 13 to 14 setae on each side (*P. b.:* 22 to 25 setae on each side). In the present species there is a wide interval between the three anteromedian setae and those more laterally placed, whereas in *P. bidactylus*, this wide gap was not found. Width of scutum equal to .67 of the *median* length. Sensilla situated at .40, appearing
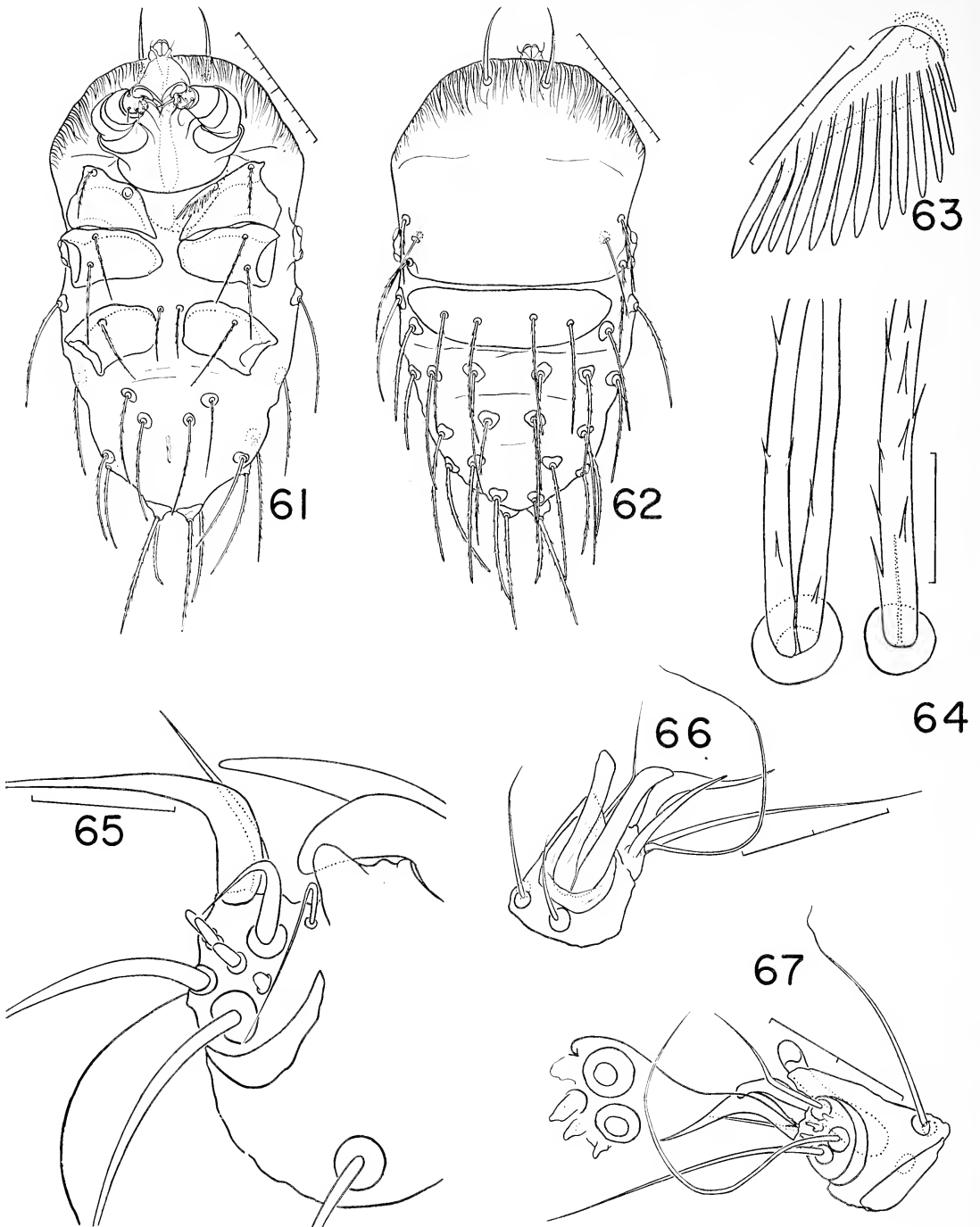
FIGS. 61–67. *Paratrombium quadriseta*, n. sp., larva: 61, venter; 62, dorsum; 63, medial seta of coxa I; 64, anomalous postscutal seta and normal homologue; 65, tibia and tarsus of palp, posterior; 66, tibia and tarsus of palp, dorsal; 67, tibia and tarsus of palp, posteroventral.

minutely barbed at magnifications of 600 ×
(Fig. 76). Beginning at .32 and extending an-
teriorly is a deep furrow, reaching to the level
of about .08; beyond this level are three setae
as in the previous species. Narrowest point
of scutum at .22 to .27. Punctate cuticle ex-
tending very nearly to the posterior end of
the scutum, which is not markedly swollen
as in *P. bidactylus*, and the pigmented cuticle
ends in front of the depression in the end of
the crista. In the portion of the scutum be-
tween .25 and .68 of the specimen examined,
there were 30 setae, 15 on each side (*P. b.*:
31 setae here, in the one specimen). Crista
metopica tapering somewhat more gradually
behind area sensilligera than in preceding
species. Ocular plates and dorsal hystero-
somal setae as in *P. bidactylus*.

Ventral surface of the body showing no
significant differences from *P. bidactylus*, ex-
cept for a slightly more sparse vestiture of the
coxae and genital sclerites. Genital sclerites
bearing 39 and 37 setae (*P. b.*:48–55), para-
genital sclerites bearing 26 and 29 setae (*P. b.*:
about 55 on each side). The form of these
setae is essentially identical in the two spe-
cies, however. Gnathosoma in ventral view
resembling that of *P. bidactylus*, but slightly
larger; rostrum not reaching to distiventral
margin of femur (in *P. bidactylus* the rostrum
extends to a point about half way between
the distiventral and distidorsal margins of
the segment).

Chelicerae virtually identical with those of
P. bidactylus, except that the row of denticles
is straight throughout its length, whereas in
the preceding species it is sharply deflected
about the middle. Palpi virtually identical in
general size and form with those of the pre-
ceding species. Tibia with large unidentate
odontus but without paradont. One feebly
developed ctenidium present, consisting of
about four setae somewhat longer, heavier,
and smoother than the others, extending
along the anteroventral margin at the inser-
tion of the tarsus. Eupathidia of tarsus ex-
tending from .68d to .95v, solenidion at .80

to .85p. The eupathidia of the palpal tarsus of
this species are noticeably more numerous
(17–19) than in *P. bidactylus* which has only
11 on each tarsus. With such a difference as
this, it is doubtful that study of larger num-
bers of individuals would show much over-
lapping in this character.

Tarsus I 423 μ long, 144–149 μ high,
length/height 2.84–2.94; tibia I 261–266 μ
long, tarsus I/tibia I 1.59–1.62 (single
specimen).

LARVA: Idiosoma (Figs. 61, 62) 356 to 383 μ
long, 189 to 203 μ wide, length/width 1.87
to 1.92; average 374 μ by 197 μ, length/
width 1.88 (five unengorged larvae). Scutum
essentially as in *Paratrombium bidactylus;* pro-
sensillar setae completely smooth, somewhat
spindle-shaped, with thickest portion about
one-fourth of the way out on the shaft. An-
terior portion of scutum striate, posterior
portion densely and uniformly punctate.
Sensilla appearing smooth at low magnifica-
tions but faintly pectinate under higher mag-
nifications. Ocular plates bicorneate, the an-
terior cornea larger than the posterior. Post-
scutum bearing four setae in a transverse row.
(In some individuals of *P. bidactylus*, one of
the setae of the postscutum may be dupli-
cated, but in these cases the placement of the
supernumerary seta is quite different since it
is not aligned with the two normal setae.)
Remaining dorsal and marginal setae identical
in number and position with those of *P.
bidactylus*, so that there is a total of 26; venter
with 6 peripectinate postcoxal setae, making
a total of 32 postcoxal and postscutal setae.
Except for the setae of the postscutum, all of
the setae are borne on individual punctate
sclerites. Membranous cuticle faintly striate,
but the striae do not make any striking pat-
tern. Ventral surface showing no significant
difference from *P. bidactylus*. One dissection
provided considerable insight into the struc-
ture of the so-called urstigma (or "urpore").
In Figure 73 (dorsal view) the urstigma is
seen to consist of an elliptical cavity or ring,
with no opening whatever on the ventral sur-
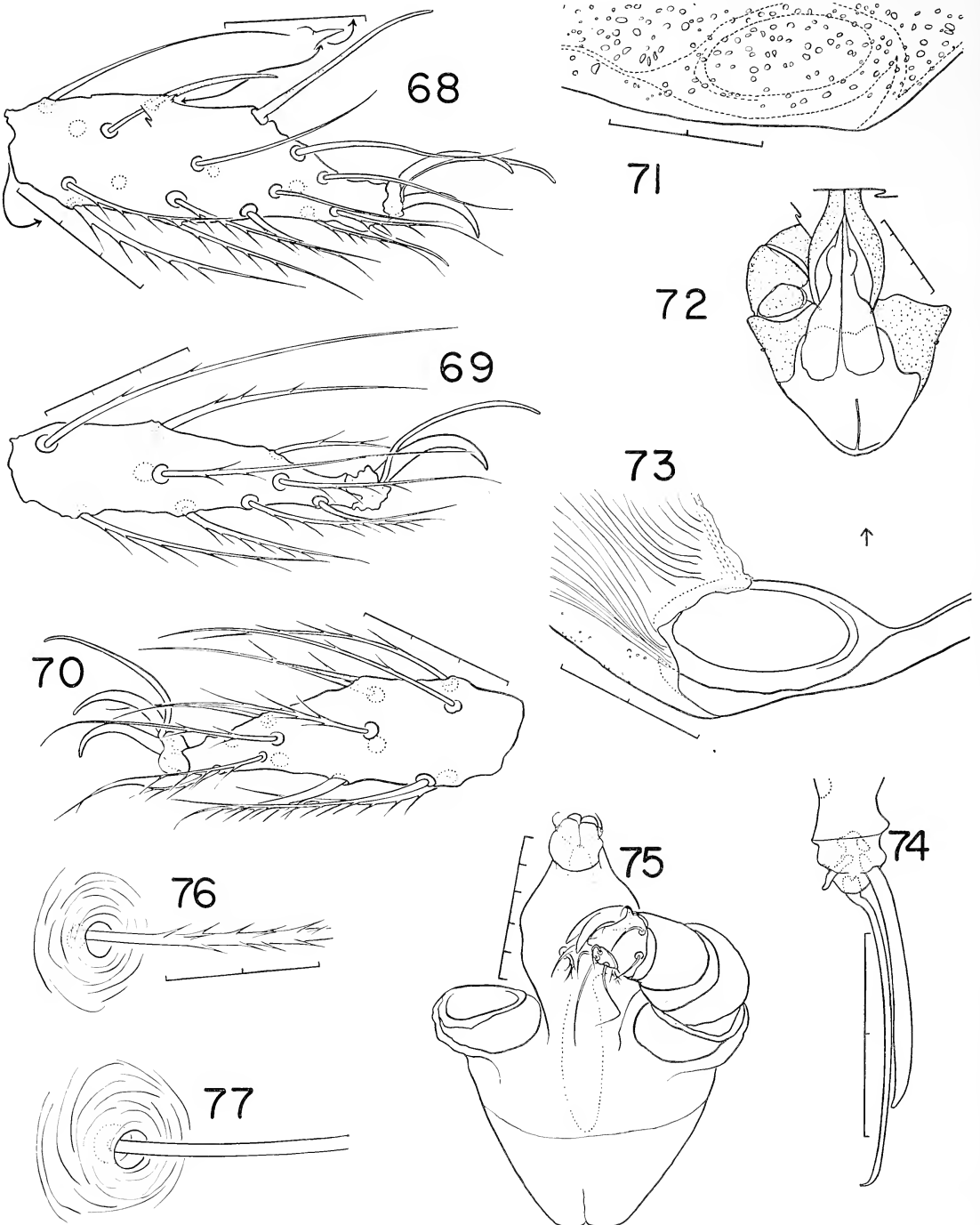
FIGS. 68–75. *Paratrombium quadriseta*, n. sp., larva: 68, tarsus I, posterior; 69, tarsus III; 70, tarsus II; 71, urstigma, left coxa I, ventral; 72, outline of gnathosoma, dorsal; 73, urstigma, detached coxa I, dorsal; 74, tarsal claws III, right side, dorsal; 75, gnathosoma, ventral.

FIG. 76. *Paratrombium quadriseta*, n. sp., female, base of sensillum.

FIG. 77. *Paratrombium bidactylus*, n. sp., female, base of sensillum.

face (Fig. 71). The posterior wall of the urstigma lies in a slitlike pouch between the posterior margin of coxa I and the overlying membranous cuticle of the ventral body wall. An apodeme arises from the anterior margin and extends in an anterior direction. The punctate cuticle posterolateral to the urstigma in Figure 73 is the upturned margin of coxa I which continues directly with the striated membranous cuticle of the body wall. Although the function of the urstigma is not apparent from this, it obviously is not a respiratory opening. The term "urpore" is a misnomer, but "urstigma" appears to be acceptable as long as it is understood that it is not a "stigma" in the sense of a respiratory opening. Details of lateral portion of propodosoma as shown for *P. bidactylus* (Fig. 34). Base of gnathosoma as described for *P. bidactylus*, except that the supracoxal setae appear to be consistently more lateral in position, and also shorter and blunter. Palpi as in previously described species, except for chaetotaxy of tarsus. The tarsus bears four long setae dorsally, one of which is very slender, another heavy and scythe-shaped, and the other two intermediate in form. The two ventral setae are flexible and very elongate. Between the four dorsal and two ventral setae is a transverse row of four short, peglike setae. One of these is presumably the solenidion, probably the most posterior one, but all four are so similar in form and size that it is impossible to say for certain which one is the true solenidion. Podocephalic canals very short, extending scarcely to the level of the anterior margin of coxa I. Rostrum as in *P. bidactylus*.

Although the larva of *P. bidactylus* is larger than that of *P. quadriseta*, its palpal tarsus appears to be both actually and relatively smaller. In one specimen of each of the two species, the maximum diameter of the base of the tarsus measured 10 and 13 μ respectively, which is a considerable difference in a structure of this small size. In *P. quadriseta*, four small setae can be resolved with little or no difficulty, arranged in a straight row across the distiventral surface of the tarsus. In *P. bidactylus* on the other hand, only two setae can be seen with any certainty here, and these are noticeably compressed between the bases of the larger setae and the tarsus (Figs. 35, 67).

Femora I–III undivided, basiventral seta of all femora very delicate, only about half the diameter of the other setae on the segment. Chaetotaxy of legs similar to that of *P. bidactylus*, at least so far as the number of setae on the various segments is concerned. Solenidia of patella I at .37d and .54d, vestigial seta at .80d. Tibia I with solenidia at .50d and .74d, a vestigial seta at .88d. Tarsus I with solenidion at .35–.48d, e_d at .64–.71, and e_p at 0.94, famulus at .38–.55. Patella II with a single solenidion at .40, vestigial seta at .73; tibia with two solenidia, at .39d and .61d. Tarsus II with solenidion at .40–.50d, famulus at .35–.49d; eupathidia lacking. Patella III with solenidion at .47, tibia without solenidia. Tarsus III typically bears four whorls of normal setae containing three, four, four, and two setae each (total 13), but of 8 tarsi examined, two had 14 normal setae and one had 12 normal setae. The basal whorl normally contains only three setae, but in exceptional specimens a fourth has been added. In that tarsus III with only 12 setae, the deletion occurred in the third whorl from the base of the tarsus. Tarsi I and II each has three well-developed claws, the median one more delicate and erect than the anterior and posterior claws. Tarsus III with anterior and median claw well developed, posterior claw as in *P. bidactylus*, reduced to a very minute rudiment.

TYPE LOCALITY: Riverside, California, Santa Ana River, at Camp Evans. Females found crawling on muddy bank of stream, April 23, 1955. Collected by the writer.

REMARKS: The correlation between the larva and adult of this species was established by rearing. This species is obviously closely related to *Paratrombium bidactylus*, but the dif-

ferences between them appear to be of truly specific nature. They can be differentiated immediately on the basis of the chaetotaxy of the postscutum. In view of the variation noted in *P. bidactylus* it should be expected that exceptional forms might be found which have four setae on the postscutum, although none has been seen by the writer. However, even if this were to occur, the position of the lateral setae in *P. quadriseta* is very characteristic, these forming nearly a straight line with the medial setae. There are other differences too, of a more relative nature, in the proportions of the scutum and postscutum and the positions occupied by the specialized setae of tarsi I and II. These are summarized in the preceding table of variants of larval characters.

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